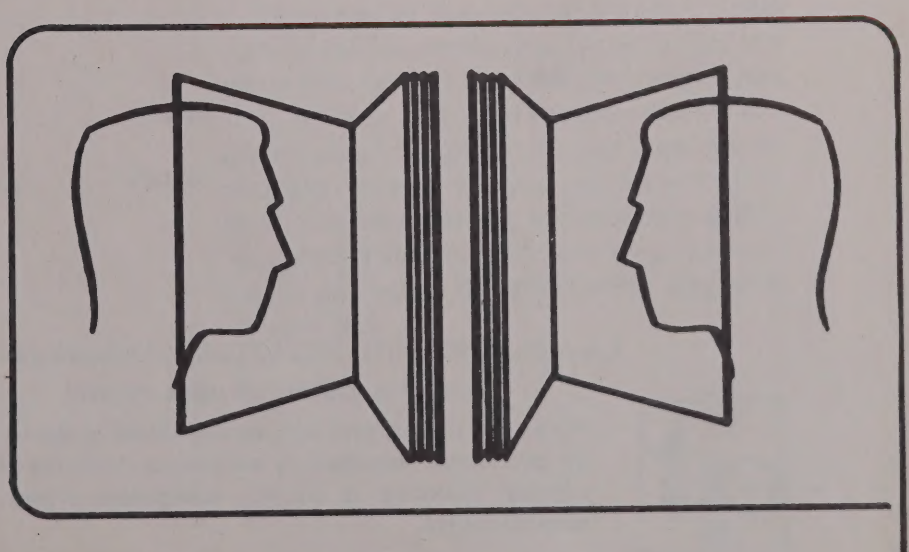
Trainee's Guide

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



PLANT ENGINEERING TRAINING SYSTEMS

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PREFACE

This TRAINEE'S GUIDE was prepared to help you achieve maximum benefit from the course of study you are about to begin. This type of course may be an entirely new experience to you. The thought of having to study without a teacher or instructor might even be disturbing. This GUIDE provides you with the help needed to gain the most from your new study program.

Whatever job you do, you have learned you should use the right tools. Not only must you use the right tools, but you need skill to use the tools. Your new course of study is a tool which will help you to do your job. This GUIDE will help you gain the skill you need to use this new tool.

Regardless of how you have studied in the past, it will be worth your while to read the pages that follow. You will find suggestions that will help you learn the information you are expected to gain from your new course of study. It will help you retain the information you have learned, increase your ability to concentrate on your studying, and organize and relate the information you learn to your job.

PLANT ENGINEERING TRAINING SYSTEMS

Electrical Measuring Instruments

Lesson 1
PRINCIPLES OF ELECTRICAL INSTRUMENTS
Electromagnetic forces; Operating principles of the PM-MC instrument; Instrument bearings, Instrument damping; Magnetic shielding; Parallax errors; Measurement values; Shunt construction and connections; Instrument sensitivity; Meter accuracy; Extending the meter range by the use of shunts; Meter design principles.

Lesson 2
D-C INSTRUMENTS
Meter selection; Use of a D-C ammeter; use of a D-C voltmeter; Accuracy considerations; Voltmeter sensitivity; D-C meter connections; Thermocouple instruments and Construction; Principles of thermal metering; Measuring KVAR with a thermal meter.

Lesson 3
RESISTANCE MEASUREMENTS
Ohmmeter operating principles; Use of the Ohmmeter; Ohmmeter calibration; Ohmmeter multiplication features; Understanding insulation resistance; Purpose of grounding; The megohmmeter; Use of the megohmmeter.

Lesson 4
A-C METER PRINCIPLES
Moving iron meters; Applications of moving-iron instruments; Damping methods; Inclined-coil instruments; Electrodynamometers (dynamometers); Electrodynamometer applications; Dynamometer operating principles; Principle parts of a dynamometer; Dynamometer circuit connections; Rectifier-type instruments; Instrument rectifier construction.

Lesson 5
A-C MEASUREMENTS
Meter selection; Split-core A-C instruments; Construction of the split-core meter; Operating principles of the split-core instrument; Voltage and current measurement; Instrument transformers; Testing current transformers; Fusing and grounding of instrument voltage transformers; Polarity markings; Current transformer connections; Safety precautions in testing instrument transformers.

Lesson 6
POWER MEASURING INSTRUMENTS
Wattmeters; Measurement of power; Watthour meters; How to read a watthour meter; Demand meters; Power-factor meters; Operating factors of power measuring instruments; Industrial analyzer; Using the Analyzer for Current and Voltage measurements.

Lesson 7
SPECIAL INSTRUMENTS
The multimeter; Voltage measurements; Current measurements; Resistance measurements; Bridge circuits; Wheatstone bridge; Capacitance bridge; Inductance bridge.

Lesson 8
INDICATING INSTRUMENTS
Types of indicating instruments; The pocket-type voltage tester; Continuity testers; Rotation tester; Phase sequence indicator; Synchronizing indicators; The synchroscope; The growler; Frequency meters.

Lesson 9
RECORDING INSTRUMENTS AND INSTRUMENT CARE
Recording instrument operating principles; Strip chart recorders; Round chart recorders; Care of instruments; Instrument connection precautions; The stroboscope and its applications.

Lesson 10
ELECTRONIC INSTRUMENTS
The vacuum-tube voltmeter, A-C voltage measurements; Resistance measurements; The oscilloscope; Oscilloscope sweep; How to use the oscilloscope; Solid-state instruments.

I PLANT ENGINEERING TRAINING SYSTEMS COURSES

There are certain basic principles and theories that are essential to understanding all the jobs you perform in your trade. In this program every effort was made to cover these principles and theories and to relate them to your job.

Your Training Unit contains the material you are to read – there is no separate textbook. It also contains the problems you are to solve and a number of exercises. This course was designed so you can complete it on a self-study basis. Your supervisor, or someone he has designated, will be available to offer assistance should you require any. He in turn can call upon PLANT ENGINEERING Training Systems if the need arises. Help is available to you just for the asking.

A. Organization and Coverage of Study Material

Each PLANT ENGINEERING TRAINING SYSTEMS COURSE is divided into a number of units. Every unit has ten lessons. The time required to complete each lesson will vary, depending on the background of each trainee.

B. Your Training Manual

The Manual you have received is intended both as a self-study guide and as a ready reference at any future time. The Manual is your property. You will be required to write in it to answer questions, and in some cases to solve problems.

C. Lesson Organization

Each lesson consists of a "text" portion which has several pages of written material and illustrations. This section is followed by a page of programed exercises (an explanation of this type of exercise will follow). This sequence is then repeated. A summary of key points is included in each lesson. The last section of each lesson is a self-check quiz. The material contained in the text of the lesson is information that is considered essential to understanding the topics of the lesson.

D. Programed Exercises

The programed exercises, which follow the text material in each lesson of your Manual, consist of a series of short statements or problems called FRAMES. Each frame requires that you make a response either by writing in a word or words, a formula, or a number. The correct response has been placed to the right of each frame (in the column that has been printed in color). A reference to the place in the text where the answer can be found (the paragraph or Fig. No.) has also been placed in this answer column.

Inserted in your Guide is a REVEAL KEY. The color of this key is matched to the column of the programed sections which contain the correct responses. The key is designed so it reveals the frame on which you are working and conceals both the answer (to the right of the frame) and the following frame. After you WRITE your answer in the space provided, move the REVEAL KEY down and read the correct response in the right-hand column. If you have made a mistake, erase your answer and REREAD the statement problem and WRITE the correct response. If you feel you have an answer that is equally correct, check with your supervisor.

It is important that you write your answer in the space provided BEFORE you look at the correct response. Do not take the "short cut" of merely reading the answers to the programed exercises, without actually writing out your answers, as this will reduce the amount of information you will retain.

The length of the space or the number of spaces will OFTEN give you a hint as to the length of the answer. In most cases you should know the correct answer and therefore not need the hint. You should not depend upon the length of the space to guide you to the right answer. In some frames you need only indicate your answer by circling your choice. Be sure you make your selection of the answer BEFORE you uncover the correct response.

E. Testing Program

The tests incorporated in each unit of study should assist both you and your supervisor to

evaluate your progress in the course of study. The tests consist of multiple-choice questions. Each question has four possible answers from which you must choose.

1. Unit Pre-Test

In order to help determine the training requirements of your company, PLANT ENGINEERING Training Systems developed the test which you may have taken BEFORE you were given your Training Manual. The results of your test will be used to determine the assistance you will need in this course.

2. Self-Check Quizzes

These are quizzes which you can complete "on your own." They are included at the end of each lesson to help you determine how well you have studied the lesson. The correct answers to these quizzes are printed on the last page of the lesson. Just as you have been advised to do in the programed exercises, DO NOT check your answers until AFTER you have completed the quiz.

3. End-of-Unit Test

You will be given an End-of-Unit test after you complete each unit of the course. This test will consist of 50 multiple-choice questions based on the material you have studied in the ten lessons of the unit. You should be able to complete the test in approximately one hour.

4. Retesting

In the event you do not do well on the first End-of-Unit test, a second test may be administered. However, BEFORE you attempt the second End-of-Unit test, you should spend additional time in rereading and studying all the material in the lessons on which you are being tested.

F. Unit and Course Certificate

After you successfully complete a unit of study, which includes achieving a satisfactory score on the End-of-Unit test, you will receive a certificate of completion. At the completion of the entire course, you will receive a certificate of course completion which will include an outline of the units covered in the course.

G. Supplementary Reading Material

If you feel, after you have completed reading the material in your lesson, you would like additional information or you would like to do more extensive studying on certain topics, your supervisor who is conducting your training program can provide you with a list of supplementary reading material. This list has been prepared by PLANT ENGINEERING Training Systems.

II HOW TO GAIN THE MOST FROM YOUR COURSE OF STUDY

Each of the lessons in your course has been carefully planned to make your understanding of the various subjects as easy and meaningful to you as possible. A certain amount of effort on your part is required if you are to obtain the maximum benefit from the course. This places a greater responsibility for learning on you, but your efforts will be well rewarded.

A. Establishing Good Study Habits

The key to success in this course is to develop good study habits. If possible, try to set aside a specific time each day to study in an area where you can concentrate without being disturbed. Ideally, you should select a time when you are at your mental peak; a period when you feel most alert. If all these conditions can not be met, make every effort to find a study area where you can concentrate without interruptions.

In your first course lesson you may experience a little difficulty in adjusting to a study program of this nature. However, once you become familiar with the program, you should have little difficulty in completing the lessons.

Here are some steps you should follow to help you get the most from your lessons:

STEP ONE: Before you start reading each lesson word-for-word, glance through the lesson. In the survey you should:

a. Read the titles, headings, and subheadings, As you do this, see if you are familiar with the various topics and whether you can notice the relationship of the topics and how they are arranged.

b. Look closely at the illustrations, drawings, charts, or schematics that have been included in the lesson.

c. As you proceed from page-to-page, read the first and last sentences in the paragraphs.

You should be able to complete the preliminary survey in a matter of five or ten minutes. This quick review should give you a good idea of the important points, and you will know what to expect as you begin a careful study of the lesson.

In the survey you make of your future lessons, see how the new material ties in with the material you have studied in the previous lessons.

STEP TWO: Read each paragraph carefully. Be sure you understand each sentence. This will require you to:

a. Look up words with which you are not familiar — this may occur occasionally.

b. Understand each sentence.

c. Try to summarize each paragraph in a few words or simple sentences.

d. Stop and consider what you have learned after reading a paragraph or a page.

STEP THREE: Take notes on the material you have read to help your memory. Instead of taking notes, you may prefer to underline the important points in each lesson. After you have underlined the important points, you will be able to spot these points when you review the material. A word of caution: Don't underline too many points. Set up your own system of distinguishing between main points and subordinate ones.

There are a number of methods you might consider to set up your system of text outlining. You might identify important points by using different colored pens or pencils. Certain points can be enclosed in brackets or parenthesis. Important points can be identified by numbers or letters. Be sure you have a reason for making your marks because a large number of marks will not necessarily indicate how well you read or understand the text.

Do not take notes on your lesson or underline the important points until AFTER you have read a paragraph or a page of text material. If you start writing notes or underlining material as you read your Manual, you may over-mark your Manual and miss some of the important relationships in the subject, or you may lose continuity in your reading.

STEP FOUR: Before you take the self-check quiz, at the end of each lesson, REVIEW the key points in the lesson. The underlining or note-taking you have done in your Training Manual will help you remember the major points in the lesson.

After you have completed all the lessons in a unit you should make a careful review of all lessons. Your review should include rereading the programed sections and the self-check quizzes. You should now be ready to take the End-of-Unit test. If, in your REVIEW, you find there are some subjects that do not seem clear to you, reread the material covering the subject.

B. Improving Your Reading Habits

You can increase your reading speed and save study time, without reducing your understanding, if you "push" yourself to read faster. As you start to read your lesson, try to see more than one word — increase your view to include phrases or groups of words. As you do this, try to get the meaning of the phrase you have read, rather than the meaning of individual words. A common error many people make as they read a sentence is to repeat words silently. As you can see, if this is done you will reduce your reading rate. See how long it takes you to read and understand a page in your lesson, then try to do better on the next and succeeding pages. By knowing how long it has taken you to complete the first page, you will be able to gradually read faster and keep your speed for longer periods of time.

C. How to Take Your Tests

The questions in the self-check quizzes are multiple-choice questions. This type of ques-

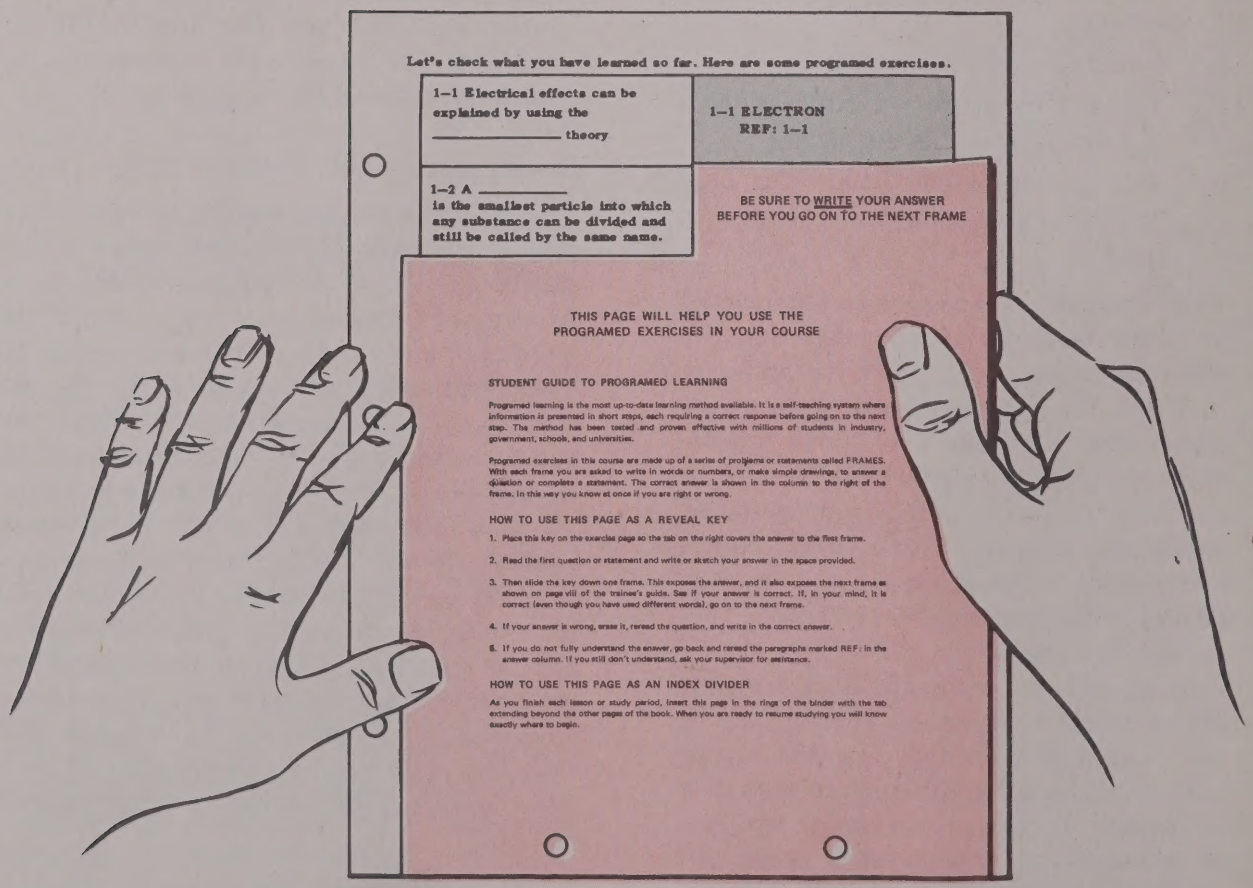
tion is used in each lesson so you have an opportunity to practice test taking. The End-of-Unit tests are also of the same type.

The multiple-choice questions consist of a direct question, a complete sentence, or an incomplete statement followed by four possible answers, one of which completes or answers the question. In some cases only one answer is correct. In others, one of the choices is the best answer.

The key to taking any test is reading each question carefully. If the answer that comes to your mind does not appear, carefully reread the question and the choices provided. If you can not determine what the desired answer is, go on to the next question. After you have selected the answer to all the questions for which you are sure of the correct response, then go back to the questions you were not able to answer.

After you have answered all the questions you can, you should then review the quiz or test. It is very possible to make mistakes in this type of test, either by misreading questions, or by not properly checking the answer you selected.

The tests which have been included in the course, for the most part, are not competitive examinations. You are only competing with yourself. You can take these quizzes or tests with confidence if you are well prepared.


Let's check what you have learned so far. Here are some programed exercises.
1–1 Electrical effects can be explained by using the _____ theory
1–1 ELECTRON
REF: 1–1
1–2 A _____ is the smallest particle into which any substance can be divided and still be called by the same name.
BE SURE TO WRITE YOUR ANSWER BEFORE YOU GO ON TO THE NEXT FRAME
THIS PAGE WILL HELP YOU USE THE PROGRAMED EXERCISES IN YOUR COURSE
STUDENT GUIDE TO PROGRAMED LEARNING
Programed learning is the most up-to-date learning method available. It is a self-teaching system where information is presented in short steps, each requiring a correct response before going on to the next step. The method has been tested and proven effective with millions of students in industry, government, schools, and universities.
Programed exercises in this course are made up of a series of problems or statements called FRAMES. With each frame you are asked to write in words or numbers, or make simple drawings, to answer a question or complete a statement. The correct answer is shown in the column to the right of the frame. In this way you know at once if you are right or wrong.
HOW TO USE THIS PAGE AS A REVEAL KEY
1. Place this key on the exercise page so the tab on the right covers the answer to the first frame.
2. Read the first question or statement and write or sketch your answer in the space provided.
3. Then slide the key down one frame. This exposes the answer, and it also exposes the next frame as shown on page viii of the trainee's guide. See if your answer is correct. If, in your mind, it is correct (even though you have used different words), go on to the next frame.
4. If your answer is wrong, erase it, reread the question, and write in the correct answer.
5. If you do not fully understand the answer, go back and reread the paragraphs marked REF: in the answer column. If you still don't understand, ask your supervisor for assistance.
HOW TO USE THIS PAGE AS AN INDEX DIVIDER
As you finish each lesson or study period, insert this page in the rings of the binder with the tab extending beyond the other pages of the book. When you are ready to resume studying you will know exactly where to begin.

LESSON ONE

METER OPERATING PRINCIPLES

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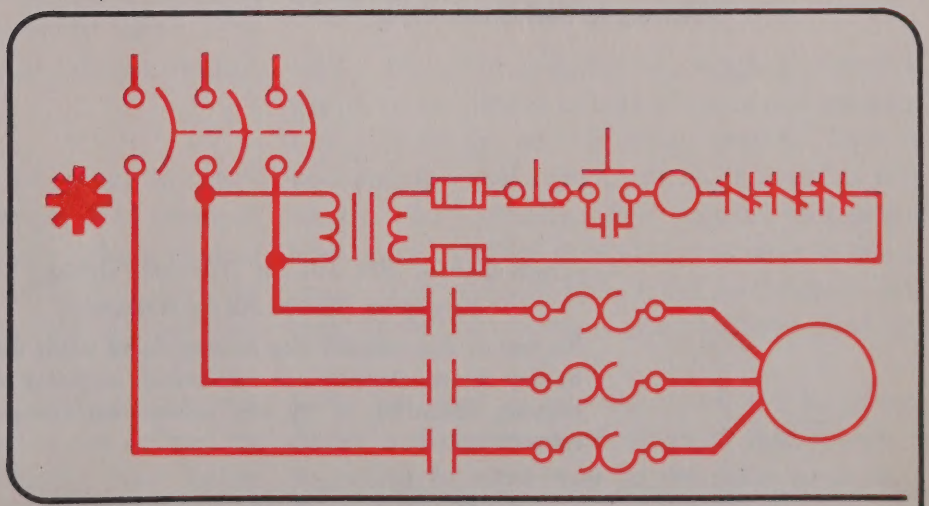
Electrical Measuring Instruments



Lesson One — Meter Operating Principles

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Lesson One — Meter Operating Principles

Preface

Next to good commonsense, measuring instruments are some of the most important tools a maintenance electrician can have.

Accurate electrical measurements are essential in electrical maintenance work. The proper instruments can tell you exactly what is going on in a circuit. However, they can also give misleading indications. This may be due to the characteristics of the instrument itself, or a lack of proper maintenance and repair. A good maintenance electrician knows the shortcomings of his equipment and pays careful attention to its condition; his job, or possibly his life, may depend on it.

A thorough understanding of the construction, operation, and limitations of the basic types of electrical measuring instruments, coupled with the theory of circuit operation, are all essential in servicing and maintaining electrical equipment.

This unit explains the operating principles, uses, and care of the more common types of electrical measurement instruments used in industrial plants.

Meter Principles

1.01 To properly troubleshoot electrical circuits, it is necessary that maintenance electricians become familiar with the common electrical instruments. Electricity requires accurate measurements of quantity. The meter is the most common quantity-measuring instrument in use today. The basic meter is used in measuring current, voltage, and resistance.

1.02 There are many types of meters, but they all have several things in common. For example, all have some form of visual scale. This is marked off (CALIBRATED) into the units which are to be measured. All have pointers (or indicator needles).

1.03 The standard units of current, voltage, and resistance (as well as other units) are defined by the National Bureau of Standards. New instruments are calibrated at the time of manufacture by comparing them with established standards. As maintenance electricians you work with ammeters, voltmeters, and ohmmeters; but you may also have many occasions to use various other types of measuring devices.

1.04 Electrical equipment is designed to operate within certain limits, usually of speed and temperature. These are its "efficiency" levels. To help you maintain the equipment so it operates efficiently, the manufacturer supplies instruction books and technical sheets for each piece of equipment. This information includes performance data such as voltage, current, and resistance readings.

1.05 A good understanding of the functional design and operation of electrical instruments is important to allow you to use these tools more effectively. In electrical maintenance work, the

following instruments are commonly used to determine that the circuits of a piece of equipment are operating properly:

1. An AMMETER measures the amount of CURRENT flowing in a circuit.

2. A VOLTMETER determines the VOLTAGE existing between two points in a circuit.

3. An OHMMETER measures total or partial circuit resistance and CIRCUIT CONTINUITY.

4. A MEGOHMMETER measures insulation resistance.

1.06 You will probably also use a wattmeter to determine the total POWER being consumed. And to measure the ENERGY consumed by certain equipment or circuits, you will probably use a WATT-HOUR or KILOWATT-HOUR meter.

1.07 For measuring other quantities you will have to use the appropriate instrument. To use that instrument properly, you must be aware of its capabilities. In each case, the instrument indicates the value of the quantity being measured. It is up to you to interpret the result in a manner that helps you understand how the circuit is operating.

Electromagnetic Forces

1.08 All meters have some form of indicating device. The basic indicating device used in instruments which measure current and voltage is called a GALVANOMETER. Like many other indicating devices, this device makes use of the magnetic field generated by current flow. The following explanation of some of the properties of magnetism and electromagnetism will help you understand the basic operation of meters. (REF: Unit 1, Lesson Four.)

1.09 All meters require current flow to cause movement of the pointer. Some meters use permanent magnets which work in conjunction with current flow to move the pointer. Others use no permanent magnet, only coils, to produce the magnetic field. Regardless of the meter type, opposing magnetic fields are used to activate the pointer.

1.10 When a conductor is wound to form a coil, the current in adjacent turns is in the same direction. Therefore, the flux from individual turns is additive. Increasing the number of turns increases the number of flux lines and thereby the intensity of the coil's field.

1.11 The strength of the magnetic field around a conductor carrying current is governed by the strength of the current. The more current, the stronger the magnetic field. When a conductor is wound in the form of a coil, this relationship between current and flux still exists. Increasing the current increases the flux around the coil's field.

1.12 When a soft iron core is placed in a coil, the number of flux lines is greatly increased compared to those present with an "air" core. Note that the additional lines of force (flux) are produced by the magnetization of the iron core and not by an increase in field intensity. (Field intensity can only be increased by increasing the current or the number of turns.)

1.13 If a magnet is shaped so its poles are close together, a magnetic field exists between these poles.

Operating Principles of the Permanent Magnet-Moving Coil Instrument

1.14 Most meters you will use are made with the same type of meter movement. It contains a galvanometer which uses a permanent magnet and a moving coil. It is called the MOVING COIL GALVANOMETER. Nearly all modern meters use this type galvanometer.

1.15 All galvanometers work on the principle of magnetic attraction and repulsion. "Like poles repel (each other) and unlike poles attract (each other)." Or, two magnetic north poles will repel each other, as will two magnetic south poles, while a north pole and a south pole will attract one another.

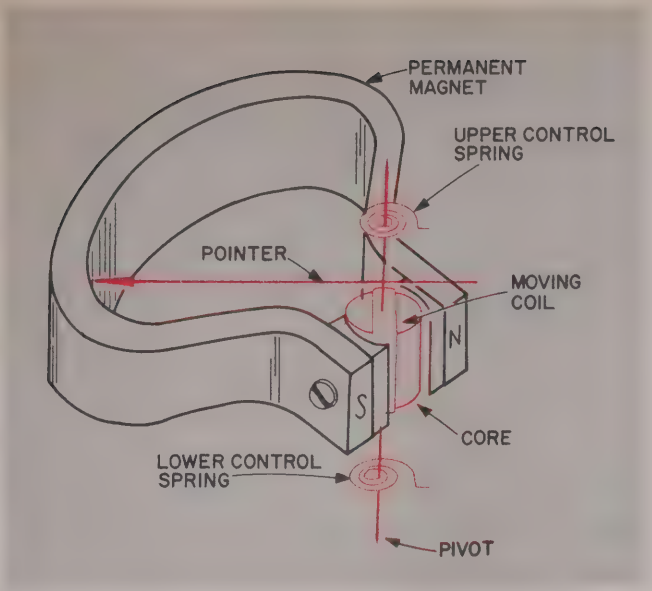


Fig. 1-1. Basic parts of a PM-MC instrument.

1.16 Galvanometers are useful in laboratory measurements of extremely small currents, but they are usually not portable, compact, or rugged enough for industrial use. A modern meter movement uses a type of galvanometer that is portable, compact, rugged, and also easy to read – the moving coil galvanometer.

1.17 This type of meter movement is commonly called the permanent-magnet moving-coil (PM-MC) movement (see Fig. 1-1). It is called the D'Arsonval movement after D'Arsonval Deprez, who invented it.

1.18 The operation of the permanent-magnet moving-coil instrument is relatively simple. It depends upon the interaction of the magnetic field of a permanent magnet, and the magnetic field of a coil. The coil is mounted on a shaft which rotates between two jeweled bearings. The coil is positioned to turn against a calibrated spring. An attached lightweight pointer turns with the coil to indicate the amount of current flow.

1.19 Balance springs on each end of the shaft exert opposing forces on the coil. By adjusting the tension of one spring, the meter pointer can be adjusted to read zero on the meter scale. Rotation of the meter coil causes one spring to tighten while the other spring loosens. Calibration of the springs provides the accuracy. In addition, these springs are also used to carry current from the meter terminals to the moving coil.

1.20 For the turning force to be applied uniformly as the current increases, the magnetic poles are arc-shaped to match the circumference of the coil. This keeps the coil a uniform distance to the north and south poles of the permanent magnet. The amount of current required to turn the meter pointer to full scale deflection depends upon the strength of the magnet and the number of turns of wire in the moving coil.

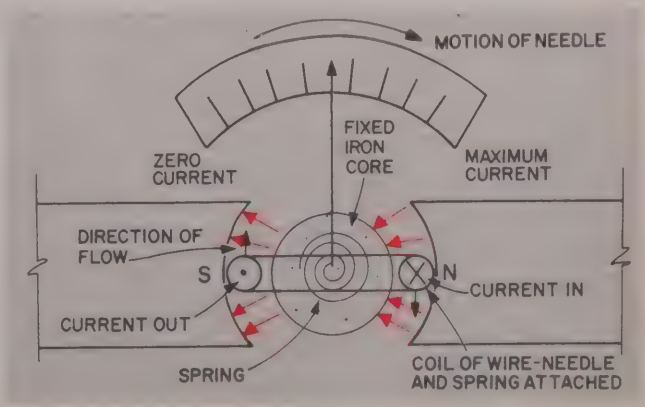
1.21 The two principal parts of the PM-MC galvanometer are the permanent magnet and the movable coil, often called the armature. Other parts are the soft steel core, which reduces the total air gap between the magnetic poles; the pointer attached to the coil, which moves with it; the scale, on which the pointer indicates the magnitude of the quantity being measured; the shaft on which the coil is mounted; and the jeweled bearings at each end of the shaft.

Moving Coil Operation

1.22 Current passing through the coil produces a magnetic field which counteracts that field produced by the permanent magnet, and thus supplies a deflecting, or turning force for the indicator. The coil turns until the opposing forces are balanced and the indicator comes to rest. The pointer indicates, on the instrument scale, the amount of current in the coil, as illustrated in Fig. 1-2.

1.23 In instruments of conventional design, the springs hold the coil in a position with one side of the coil near the edge of the adjacent pole face. This is illustrated in Fig. 1-3 and is the zero position.

Fig. 1-2. Result of current flow in a D'Arsonval meter.



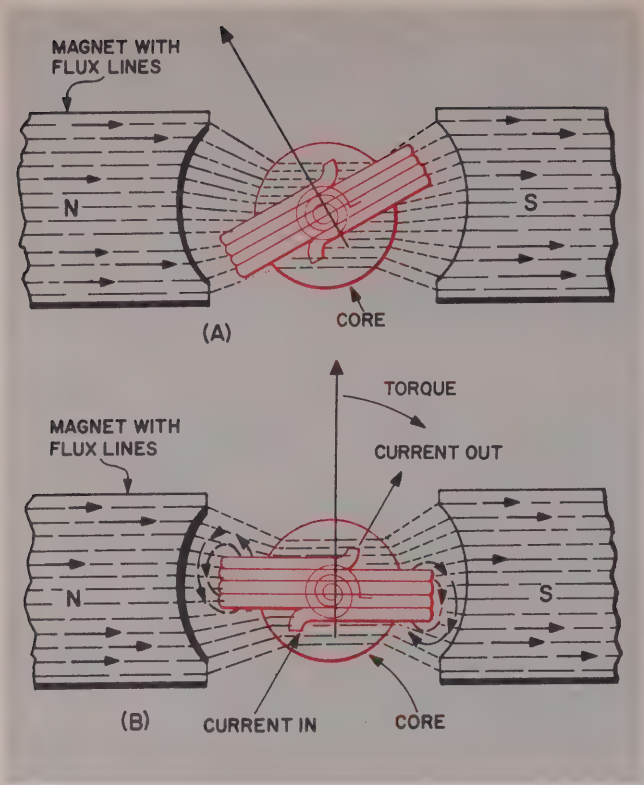


Fig. 1-3. PM-MC operating principles.

1.24 As current through the coil increases, it counteracts the permanent magnet field and causes the coil to rotate, moving the indicator toward full scale deflection.

1.25 Maximum current indication is reached when the coil side has passed across the pole face. In instruments of conventional design, this usually provides 90 to 100 degrees angular deflection. In instruments designed to measure currents of both positive and negative polarity, the balance springs are set so the zero position of the coil is halfway across the pole face.

1.26 Because the moving coil has a fixed number of turns, the coil field strength is in DIRECT PROPORTION TO THE CURRENT flowing through the coil. The strength of the permanent magnet field is CONSTANT, so the deflecting force is directly proportional to the current through the moving coil. This makes it possible to calibrate the instrument in terms of current through the coil.

1.27 Figure 1-3A illustrates the magnetic flux in the instrument when there is no current in the coil. Since there is no deflecting force, the pointer rests at zero. Dotted lines and arrows show direction and distribution of flux in the pole pieces, air gap, and core.

1.28 Figure 1-3B illustrates the magnetic flux in an instrument, with current flowing through the moving coil. As the coil flux interacts with the magnet flux, it exerts a force at both sides of the coil. This causes a clockwise rotational force about the axis which causes the movable coil to deflect away from zero.

Let's stop for a few minutes and review what you've covered so far by doing the first programed exercise. Take your REVEAL KEY and put it on the next page in such a way that only the first programed instruction question appears. Write your answer in the space provided. When you have done so, slide the reveal key down so that you can see the printed answer. Compare your answer with ours. If they don't agree, review the paragraphs or illustrations identified by the reference numbers in the answer space. If you still have a question or it's not clear, check with your study supervisor.

Use these programed exercises to help check your learning progress.

1-1. Name the meter used to measure each of the following electrical values. Current: _____ Voltage: _____ Resistance: _____	1-1. Current: AMMETER Voltage: VOLTMETER Resistance: OHMMETER REF: 1.05
1-2. A meter that measures electrical power is called a _____ .	1-2. WATTMETER REF: 1.06
1-3. The basic indicating device used in voltage and current measuring instruments is called a _____.	1-3. GALVANOMETER REF: 1.08
1-4. Before the pointer of any electrical meter will move, _____ must flow in the coil.	1-4. CURRENT must flow to create a magnetic field REF: 1.09
1-5. How is the magnetic field of a coil affected, if it has a soft-iron core? _____	1-5. The number of LINES OF FORCE (or FLUX) is INCREASED REF: 1.12
1-6. The D'Arsonval movement is frequently called PM-MC. What do these letters stand for? P _____ M _____ M _____ C _____	1-6. P – PERMANENT M – MAGNET M – MOVING C – COIL REF: 1.17
1-7. Name the two principal parts of a PM-MC galvanometer. _____ _____	1-7. A PERMANENT MAGNET A MOVING COIL, or armature REF: 1.21
1-8. Because the moving coil of a PM-MC type meter has a fixed number of turns, and the strength of the magnet is constant, the deflection of the meter is _____ proportional to current flow. *(directly/inversely)*	1-8. Meter deflection is DIRECTLY proportional to current flow REF: 1.26

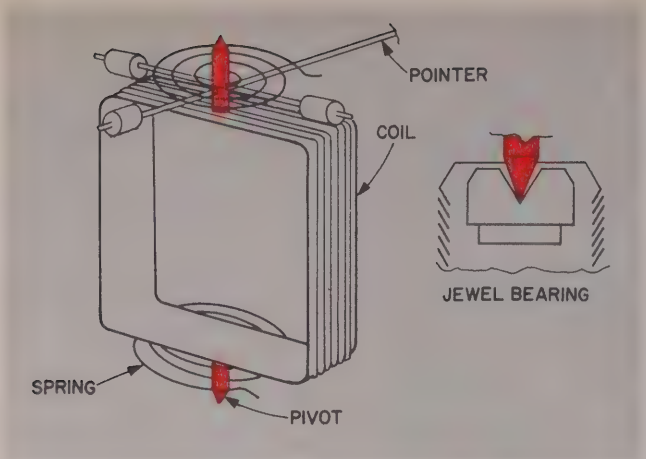


Fig. 1-4. Simplified view of a moving coil and bearing assembly.

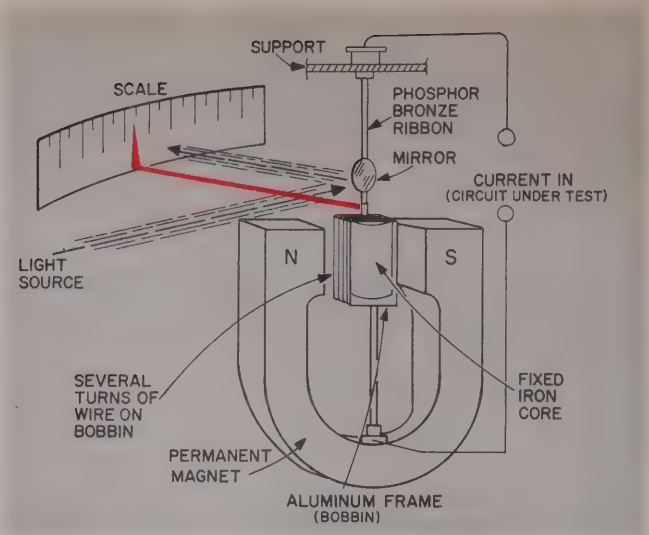


Fig. 1-5. Basic circuit and components of a PM-MC meter.

Instrument Bearings

1.29 To allow the moving coil to turn with as little friction as possible, the shaft of the moving coil is cone-shaped at each end and it turns in highly polished jeweled bearings. The cone-shaped pivots keep the shaft closely in position for instrument accuracy, and the bearing material (usually sapphire) reduces wear, see Fig. 1-4. Because of the small area of contact, there is very low loss from friction, and the meter responds rapidly to changes in current.

1.30 An essential in a bearing is mechanical strength. The moving system is extremely light in weight, but it is concentrated in such a small area of bearing contact that it produces bearing pressures of many tons per square inch. Dropping an instrument, or even setting it down carelessly, may increase the pressure to such a high value that the hardened steel pivot will be flattened or be distorted. The jeweled bearing may even be fractured though it is sapphire, the hardest known substance next to diamond. Handle all electrical instruments with great care to prevent this type of damage. It can affect instrument accuracy without the damage being apparent.

Moving Coil Damping

1.31 The moving coil is wound on an aluminum frame or bobbin. In addition to supporting the coil winding, this bobbin performs the important function of DAMPING the instrument. Damping is the term used to describe control of the swing of the moving element so the pointer comes to rest quickly at its final position. Without damping, the pointer would oscillate before coming to rest, much the same action as the needle of a pocket compass, which swings back and forth before settling into its indication of North.

1.32 The damping is achieved through the coil frame, which acts as a short-circuited turn. A voltage is induced when rotation of the coil causes the frame to cut across the lines of force of the permanent magnet. The voltage thus induced causes a flow of current in the frame. This current flow generates a field, which opposes movement of the coil, which in turn tends to bring the coil to rest quickly. This generator effect in the frame is proportional to the rate at which the coil frame cuts the field flux. Therefore, the damping is greatest when it is needed most; namely, when the current in the moving coil is changing most rapidly.

Magnetic Shielding

1.33 If the instrument is to measure the current in its moving coil accurately, interfering influences must be avoided. Stray magnetic fields can intensify or oppose the field of the instrument's magnet, and the resulting field intensity then differs from that intended by the instrument designer. Or, an adjacent mass of magnetic material can bypass some of the magnetic flux, changing the field strength and result in an incorrect indication of coil current. These possible errors are avoided by shielding the instrument — that is, by enclosing

the magnet and the moving coil in a cup or shield of soft iron or other high-permeability material. The shield provides a low reluctance path for outside magnetic fields and keeps them from affecting the accuracy of the instrument. Magnetic shielding also confines the flux of the instrument magnet, preventing its interaction with fluxes in adjacent instruments, thus permitting close grouping of shielded instruments.

Parallax Errors

1.34 The instrument scale upon which the pointer indicates measurement is mounted under the pointer, and it is graduated for ease of reading. The number and fineness of graduations depend upon the following: (1) the length of the scale, (2) the distance from which it is to be read, and (3) the accuracy rating of the instrument. Where highly accurate readings are required, a mirror next to the scale graduation is sometimes provided. To read this instrument, the operator aligns the knife-edge pointer with its reflection and is therefore sure that the reading is being taken at the correct point on the scale. The reflecting method illustrated in Fig. 1-5 is sometimes used to illuminate the pointer's indication. Another type of scale designed to minimize error in reading has the graduated portion raised to the level of the rounded pointer tip, so that readings can be taken accurately from any angle.

1.35 In less expensive meters, no special provision is made to prevent angular viewpoints which lead to PARALLAX errors. In using less expensive meters, you must be careful to sight straight on the pointer, and not from an oblique angle. The pointer is sometimes turned at the end to present a knife edge, which helps you to do this properly.

Measurement Values

1.36 In a permanent-magnet moving-coil instrument, the deflection of the moving member depends upon the amount of current and the number of turns in the coil. Armatures designed to measure millionths of an ampere (microamperes) are wound with many turns of extremely fine wire. For currents of a higher value such as milliamperes (thousandths of an ampere) the moving coil is wound with fewer turns of larger wire.

1.37 For measurements of currents larger than those that can be carried directly through the moving coil of the instrument, a SHUNT is provided as a bypass. In this way, only a safe portion of the total current in the measuring circuit passes through the instrument. In high range milliammeters, and in ammeters of relatively low range (up to 50 amperes), the shunt is mounted inside the instrument case.

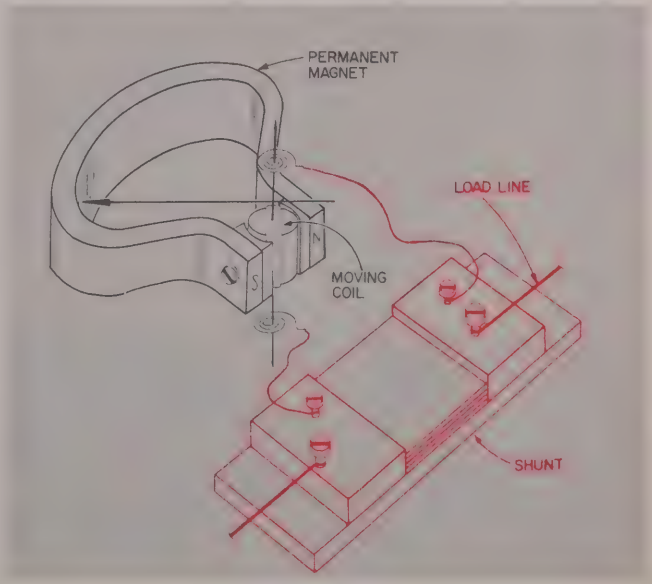
1.38 To understand how a shunt works, consider it to be a standard resistance in parallel with the instrument illustrated in Fig. 1-6. The current being measured is divided between the moving coil and the shunt according to the law of parallel resistances. Because the ratio of coil to shunt resistance is constant, the proportion of shunt current to moving coil current is always the same and the instrument can be calibrated in terms of the total current being measured.

1.39 Instruments with built-in shunts are generally constructed in ratings up to 50 amperes. The shunt is not contained in the housing, in instruments designed to measure currents over 50 amperes, because of the heat it generates.

Shunt Construction

1.40 Shunts consist of either one heavy wire, or parallel bars, connected across the meter terminals. Shunts allow only a small part of the current to

Fig. 1-6. Instrument shunt connection.



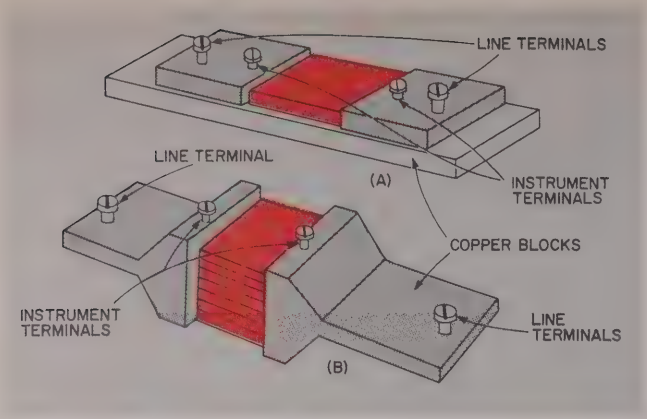


Fig. 1-7. Typical external ammeter shunts.

flow through the meter coil. Usually a 0-1 milliammeter is used with the proper sized shunt connected across its terminals to achieve the desired range of measurement. The 0-1 milliammeter is a basic meter movement.

1.41 Commonly used external shunts are illustrated in Fig. 1-7. They are standard resistance units composed of a resistance element, line terminals for the circuit connections, and drop terminals for the meter connections. The resistance element is generally made of "Manganin" alloy. Manganin reacts to temperature changes enough like copper to avoid errors, and it continues to measure accurately the flow of current as it heats up in operation. The resistance element is fastened between copper blocks to which the line and instrument connections are made. The line terminals are used for connection of conductors carrying the current to be measured. The drop terminals are smaller and they are used for connecting the instrument leads.

Shunt Connections

1.42 Remember that any voltage drop across the shunt is measured between the drop terminals to which the instrument leads are connected. Total voltage drop between the line terminals will not influence the measurement.

1.43 The drop, or instrument terminals, are those closest to the resistance strips as illustrated in Fig. 1-7. This avoids errors that could result from non-uniform distribution of current in the end blocks. This construction also exhibits very low heat loss in the shunt circuit, which decreases temperature errors.

Voltage Measurement

1.44 Although the PM-MC type instrument operates on the principles of a CURRENT measuring device, simple application of Ohm's Law allows its use in the measurement of D-C VOLTAGE values.

1.45 To do this, it is necessary to insert a series resistance in the instrument circuit for voltage measurement. The current through the moving coil must be limited to a value that will produce full-scale deflection at the maximum voltage for which the instrument is calibrated. The current in the instrument flows through a series resistor as illustrated in Fig. 1-8. The current's value is proportional to the applied voltage. The instrument scale is calibrated directly in volts.

1.46 The amount of resistance to be added for voltage measurement can be determined by the formula –

$$R = \frac{E}{I} - Rc$$

where E is the desired full-scale voltage rating. I is the full-scale current rating of the instrument, and Rc is the coil resistance. For example: if the instrument to be used has a resistance of 20 ohms with a full-scale current rating of 10 milliamperes (0.010 ampere) and the desired full-scale voltage rating is 150 volts, the total resistance must be:

$$\frac{150}{0.01} = 15{,}000 \text{ ohms}$$

Subtracting the 20 ohms resistance of the moving coil from this total shows the necessary additional resistance to be 14, 980 ohms.

1.47 For low range instruments, the resistance is mounted inside the case with the D'Arsonval (PM-MC) movement and typically consists of a resistance wire with a low temperature coefficient of resistance which is wound on either a spool or card frame. For higher voltage ranges, the series resistance may be connected externally. When this is done, the unit containing the resistance is frequently called a MULTIPLIER.

1.48 The function of a voltmeter is to indicate the difference in potential between two points in a circuit. When a voltmeter is connected across a

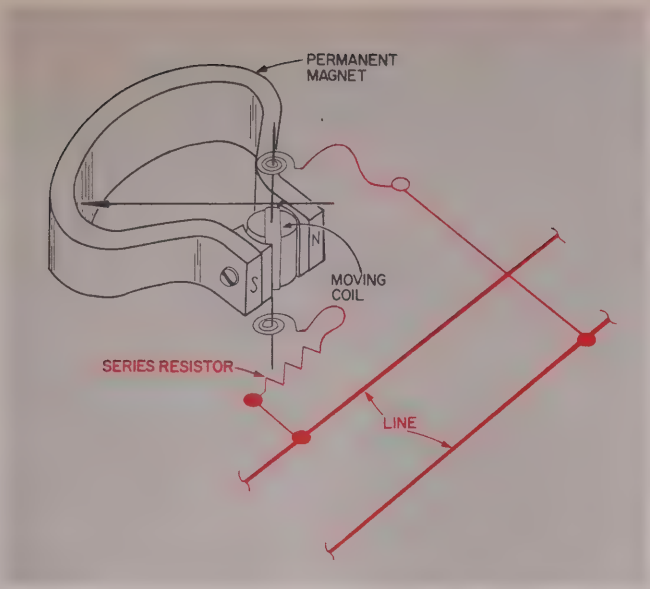


Fig. 1-8. Series resistor connection for D-C voltage measurements.

circuit, it is actually in parallel. It shunts the circuit. If the voltmeter has a low resistance, it draws an appreciable amount of current. The effective resistance of the circuit is lowered and the voltage reading is consequently lowered.

1.49 When voltage measurements are made in high resistance circuits, it is necessary to use a high resistance voltmeter to prevent the low resistance shunting action of the meter. The effect is less noticeable in low resistance circuits because the shunting effect is, of course, less.

Instrument Sensitivity

1.50 The SENSITIVITY of a voltmeter is given in ohms per volt (R/E), and may be determined by dividing the resistance of the meter (Rm), plus the series resistance (Rs), by the full scale reading in volts:

$$\text{SENSITIVITY} = \frac{Rm + Rs}{E}$$

1.51 This is the same as saying that the sensitivity is equal to the reciprocal of the current (in amperes) or,

$$\text{SENSITIVITY} = \frac{\text{ohms}}{\text{volts}} = \frac{1}{\frac{\text{volts}}{\text{ohms}}} = \frac{1}{\text{amperes}}$$

1.52 For example, the sensitivity of a 100-microampere movement is the reciprocal of 0.00001 ampere, or 10,000 ohms per volts.

1.53 Table 1-1 indicates the sensitivity of a 0 to 150-volt voltmeter, its resistance, and the current required to produce full-scale deflection.

Meter Accuracy

1.54 The accuracy of a meter is generally expressed in percent. For example, a meter that has an accuracy of 1 percent will indicate a value that is within 1 percent of the correct value. This statement means that if the correct value is 100 units, the meter indication may be anywhere within the range from 99 to 101 units.

Extending the Meter Range by the Use of Shunts

1.55 For limited current ranges (below 50 amperes), internal shunts are often used. Where a multirange shunt is employed, the range of the meter may be easily changed by selecting the correct terminal or tap having the necessary current rating. Figure 1-9 illustrates various internal shunts. To measure large current values, an external shunt must be used because of the heat it generates.

1.56 The meter current is always proportional to the load current. If the shunt has such a value that the meter is calibrated in milliamperes, the instrument is called a MILLIAMMETER. If the

Fig. 1-9. Single and multirange ammeter shunts.

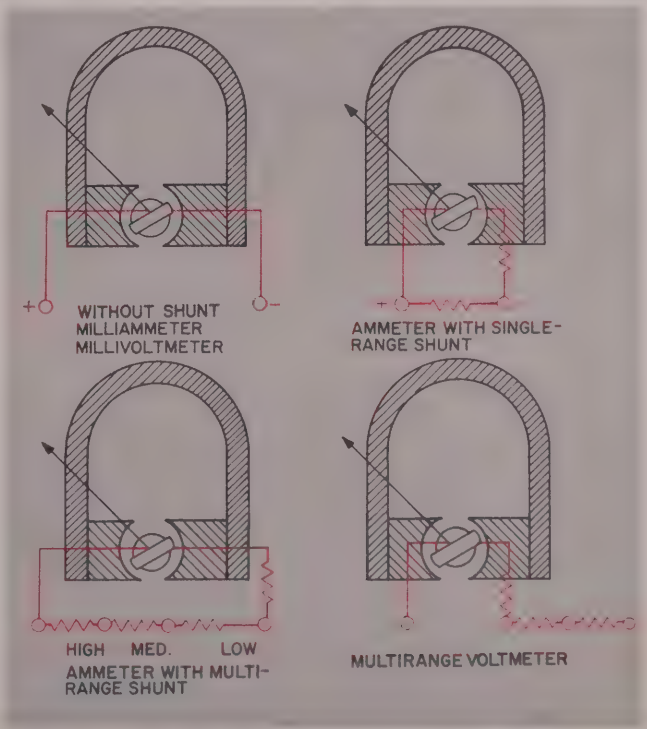


Table 1-1. Meter Movement Sensitivity		
Sensitivity	Resistance	Current to deflect full scale
1,000 ohms per volt	150 k-ohms	1 milliamp
20,000 ohms per volt	3 megohms	50 microamps
200,000 ohms per volt	30 megohms	5 microamps

shunt is of such a value that the meter is calibrated in amperes, it is called an AMMETER.

1.57 When using an external shunt ammeter, it is important to select a suitable shunt so the scale indication is easily read. For example, if the scale has 150 divisions and the load current to be measured is known to be between 50 and 100 amperes, a 150 ampere shunt is suitable. The indicator would then deflect 75 divisions for a load current of 75 amperes.

1.58 A shunt having the same current rating as the estimated normal load current should never be selected. Any abnormally high load could drive the pointer off the scale, which might damage the movement. A good choice of shunt value is that which brings the needle somewhere near the mid-scale indication when the load is normal.

Design Principles

1.59 The basic designs described in this lesson apply to all permanent-magnet moving-coil instruments. A clear understanding of these designs and their operating principles provides the foundation for understanding the operation of the various instruments you will be using in electrical maintenance work.

1.60 The simplest and most fundamental electrical instruments are the familiar panel meters used for the measurement of voltage, current, and power.

1.61 Millivoltmeters are frequently used for temperature measurement.

1.62 Recording meters are used to record readings over a period of time and to provide a permanent record of those readings. Incorporating oversize meter movements, they have limited industrial application. The indicator's pointer is replaced by a recording pen which records on a moving chart the reading being taken. The chart is marked laterally with the values being measured and longitudinally with the time intervals. Charts may be in the form of graph paper rolls or circle graphs. All of them require changing at specified intervals.

Use these programed exercises to help check your learning progress.

1-9. An electrical meter must be handled carefully, because damage to pivots and _____ _____ can affect its accuracy without this damage being noticeable.	1-9. JEWELED (or SAPPHIRE) BEARINGS REF: 1.30
1-10. What is the purpose in magnetically shielding an electrical instrument? _____ _____	1-10. Shielding PREVENTS OUTSIDE OR STRAY MAGNETIC FIELDS from affecting accuracy of the instrument. REF: 1.33
1-11. How can you prevent parallax errors when reading an electrical instrument? _____ _____	1-11. SIGHT STRAIGHT ON THE POINTER – do not look at it from an angle. REF: 1.35
1-12. The range of an ammeter can be extended by using a _____ in parallel with the instrument.	1-12. SHUNT, which is a low resistance path for the current REF: 1.38
1-13. How can an ammeter be used to measure voltage? _____ _____	1-13. A calculated RESISTANCE is added IN SERIES to limit current flow. REF: 1.44, 1.45
1-14. What is used to extend the range of a voltmeter? _____ _____	1-14. Connect a specific RESISTANCE IN SERIES with the instrument. This is called a MULTIPLIER REF: 1.47
1-15. The lower the current required for full-scale deflection of a voltmeter, the higher will be its sensitivity. A meter with high resistance will be _____ sensitive than one with low resistance. *(more/less)*	1-15. High resistance will be MORE sensitive REF: 1.50, 1.53, Table 1-1
1-16. When selecting a shunt or multiplier for use with a meter, select one that will cause the estimated reading to be near _____.	1-16. MID-SCALE REF: 1.58

Summary of Terms

AIR GAP – The space between the iron or steel elements of a magnetic circuit. In a PM-MC instrument, a coil is therein located.

AMBIENT TEMPERATURE – The temperature of the surrounding medium (usually air) which comes in contact with the apparatus.

CALIBRATION – Adjustment of an instrument mechanism or auxiliary device to obtain the correct indication.

CONTROL SPRING – A spring so designed that its torque is equal and opposite to the torque of the instrument for any deflection of the pointer within the scale range. It provides simple means for measuring the mechanical forces resulting from the flow of electric current in an instrument. Control springs are usually made of phosphor bronze, in the form of a flat spiral.

DAMPING – The dissipation of kinetic energy in the moving parts of an instrument which causes the pointer to come to rest quickly after a change in the quantity being measured.

D'ARSONVAL MOVEMENT – The mechanism of a permanent-magnet moving-coil instrument.

FULL-SCALE – The maximum normal deflection of an instrument's indicating pointer.

GALVANOMETER – An instrument for indicating or measuring small values of electrical current.

INSTRUMENT – A device for measuring the value of the quantity under immediate observation.

INSTRUMENT SCALE – The fixed part of the instrument, which presents the graduations that show the value of the quantity to be measured.

MAGNETIC SHIELDING – Protection from stray magnetic or electrostatic influences. Magnetic shielding is accomplished by containment in an enclosure of soft iron, which provides a low-reluctance path for stray magnetic flux.

MANGANIN – A copper-base alloy containing manganese and nickel; it is characterized by high resistivity and negligible temperature coefficient of resistance.

JEWELS – The cup-shaped bearings in which the pivots turn. Jewels are made of glass or synthetic, semi-precious stones.

MOVING COIL – A coil free to rotate on a pivoted shaft when it is excited by current flow.

MOVING ELEMENT – The assembly which moves as a direct result of any variation in the electrical quantity being measured.

PARALLAX ERROR – In instrumentation, parallax is the phenomenon responsible for reading errors when the viewpoint is not proper, not directly in line with the pointer and the instrument scale. Anti-parallax devices include mirror scales and scales having the graduated portion in the same plane as the tip of the pointer.

PERMANENT-MAGNET MOVING-COIL (PM-MC) INSTRUMENT – An instrument that measures the quantity of current flow in a circuit by means of an indicator which reacts to current flow in a coil mounted in the magnetic field of a permanent magnet.

PIVOT – A hardened piece of metal, ground to a point; usually mounted at the end of an instrument shaft.

SENSITIVITY – A figure that expresses the amount of error in the full-scale indication of an instrument; normally expressed either as a percentage or in ohms-per-volt.

SELF-CHECK QUIZ

1-1. Which of the following instruments is used to measure electrical current flow?

a. Ammeter
b. Voltmeter
c. Ohmmeter
d. Megohmmeter

1-2. Which of the following instruments may be used to measure electrical power?

a. Wattmeter
b. Watthour meter
c. Kilowatt-hour meter
d. All of the above

1-3. What must flow in the coil of any meter to produce a movement of the pointer?

a. Voltage
b. Current
c. Resistance
d. Watts

1-4. The two principal parts of a PM-MC galvanometer are

a. Pivots and jeweled bearings
b. Needle and scale
c. Iron core and case
d. Coil and magnet

1-5. Careless handling of an electrical meter may result in damage to its

a. Pivots and jeweled bearings
b. Needle and scale
c. Iron core and case
d. Coil and magnet

1-6. What is the purpose of shielding a meter with soft iron?

a. Keep moisture out of the movement
b. Protect the meter movement from stray magnetic fields
c. Prevent damage from rough handling
d. All of the above

1-7. The range of an ammeter may be extended by using a

a. shunt in series
b. shunt in parallel
c. multiplier in series
d. multiplier in parallel

1-8. A current measuring instrument can be used to measure voltage by

a. Adding resistance in series
b. Adding resistance in parallel
c. Using larger wire in the coil
d. Using a high resistance shunt

1-9. The range of a voltmeter may be extended by using a

a. shunt in series
b. shunt in parallel
c. multiplier in series
d. multiplier in parallel

1-10. When selecting a meter range scale to test a circuit, select the range that will indicate near the

a. top of the scale
b. mid-point of the scale
c. bottom of the scale
d. trial-and-error average point

ANSWERS TO SELF-CHECK QUIZ

1-1. a. Ammeter. REF: 1.05

1-2. a. Wattmeter. A wattmeter measures power, while a watthour meter measures energy consumed. REF: 1.06

1-3. b. Current. REF: 1.09

1-4. d. Coil and magnet. REF: 1.21.

1-5. a. Pivots and jeweled bearings. REF: 1.30.

1-6. b. Protect the meter movement from stray magnetic fields. REF: 1.33.

1-7. b. Shunt in parallel. REF: 1.38.

1-8. a. Adding resistance in series. REF: 1.44, 1.45.

1-9. c. Multiplier in series. REF: 1.47.

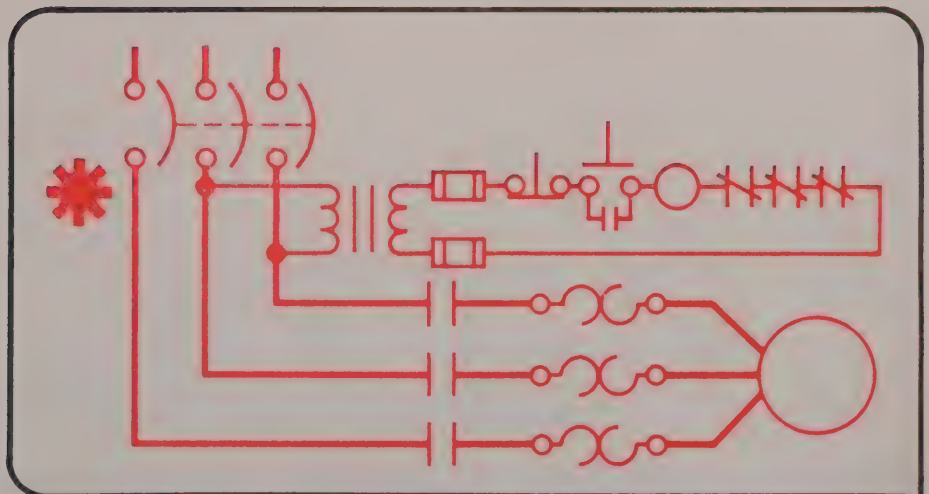
1-10. b. Mid-point of the scale. REF: 1.58.

LESSON TWO

D-C INSTRUMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Two — D-C Instruments

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Lesson Two — D-C Instruments

Preface

Instruments play a very important part in the maintenance of all types of electrical equipment. This unit covers the maintenance of electrical instruments used in industrial plants and the ways in which they *should* be used. Best results depend on the proper selection as well as the application of the instruments.

Modern plants are dependent to a great extent on the safe and efficient distribution, control, and use of electrical power. Expansion of plant facilities sometimes results in transformer or distribution circuit overload, which can be avoided if loads are properly distributed. Periodic measurement of load peaks and their frequency is the best method for determining the proper distribution of loads.

Input voltage and current-carrying capacity must be adequate in order to serve the total needs of the plant. To do this, readings of various electrical values should be made at all branch circuits, motors, controls, heaters, and other electrical devices at regular intervals.

Electrical measuring instruments most commonly used for D-C measurements are explained in this lesson.

Using a D-C Ammeter

2.01 Because the meter should not interfere with the current being measured, an ammeter must be a low resistance instrument. When connected, it must not alter the current being measured.

2.02 The purpose of an ammeter is to determine how much current is flowing in a piece of electrical equipment. The current passing through the equipment must also pass through the meter, therefore the AMMETER MUST BE IN SERIES with the equipment being tested.

Fig. 2-1. Circuit connections for a D-C ammeter.

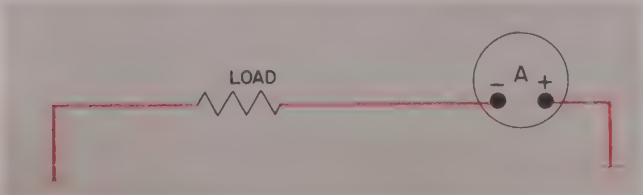
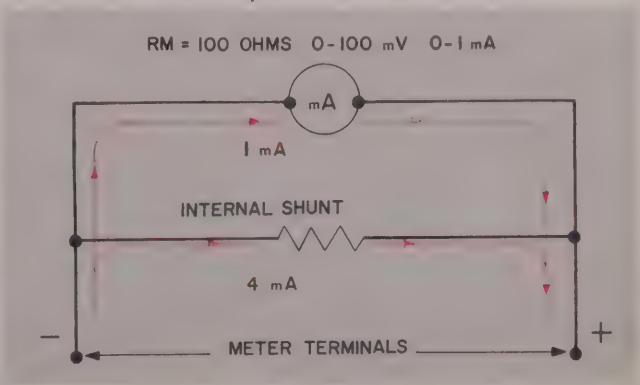


Fig. 2-2. Millivoltmeter connected through a shunt to operate as an ammeter.



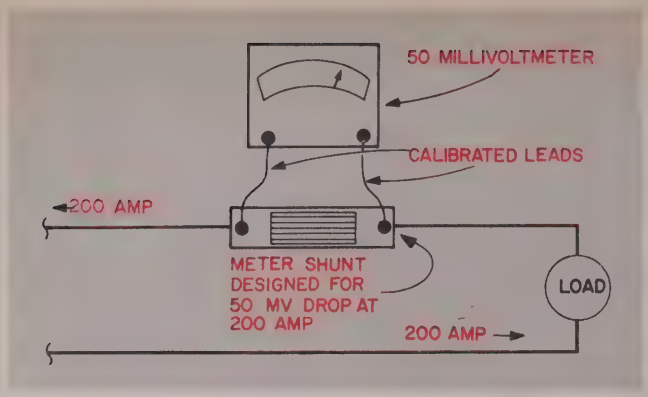


Fig. 2-3. D-C measurements of the millivolt drop across a shunt.

2.03 When measuring current, always connect the ammeter in SERIES with the load being measured as indicated in Fig. 2-1.

Extending D-C Meter Ranges

2.04 If the circuit current is known to be larger than the capacity of the meter, a shunt resistance should be connected in parallel with the meter as illustrated in Fig. 2-2. Most of the current will flow through the shunt, and only a very small, directly proportional amount will flow through the meter. The meter scale is calibrated to measure the total current flowing through both the shunt and the meter.

2.05 The shunt circuit in Fig. 2-2 is actually a low resistance conducting path placed in series with the circuit to be measured.

2.06 Shunts are usually designed to be used with a 50 millivolt meter movement. For example, they may be designated 50 mv, 200 amperes. This indicates that the voltage drop across the shunt is 50 millivolts when 200 amperes are flowing through the shunt. The meter is generally calibrated directly in amperes and it will read 200 amperes at full-scale, as illustrated in Fig. 2-3.

Selecting a Meter

2.07 The most important characteristic to consider when selecting a meter is the kind of current, A-C or D-C, it will measure. To accurately measure D-C voltage or amperage, the permanent-magnet, moving coil instrument usually is used. Where great accuracy is not required, a moving-iron meter may be used. Its operating characteristics will be explained later in this unit. For most wattage checks on D-C circuits, D-C ammeters and voltmeters do a good job. Unlike A-C ammeters, their readings are always equal to the power being drawn. (Volts x Amperes.)

2.08 Once the basic instrument has been selected, consider the range of the electrical quantity to be measured. If the approximate quantity is known, it is a simple matter to select an instrument so the reading taken will be well up on the scale. Generally, you will find the best accuracy at a point about two-thirds full-scale: keep that in mind when you select the range of the scale.

2.09 If an unknown voltage is to be measured, use a high range voltmeter or the highest range of a multirange voltmeter. If you get a low reading on that scale, then switch to a lower range (when using a multirange instrument) or select another instrument. Using a high range first will often prevent damage to the instrument. Range selection for an ammeter is actually more important than selecting the correct range for a voltmeter.

2.10 Determining the value of direct current is the first step when taking electrical measurements of D-C circuits. Usually a permanent-magnet, moving-coil instrument, such as described in Lesson One, is most adaptable.

Use these programed exercises to help check your learning progress.

2-1. So as not to affect the current, an ammeter must have _____ resistance. *(high/low)*	2-1. LOW resistance REF: 2.01
2-2. Since an ammeter measures current in a circuit, it must be connected in _____ with the circuit.	2-2. An ammeter is always connected in SERIES with the device being tested. REF: 2.02
2-3. If the current to be measured is greater than the meter rating, a _____ must be connected in parallel with the meter.	2-3. A SHUNT is connected in parallel REF: 2.04
2-4. A shunt is a _____ resistance path for current. *(low/high)*	2-4. A shunt is a LOW resistance path, or good conductor REF: 2.05
2-5. What is the first circuit characteristic you should consider when selecting which instrument to use? _____	2-5. Is the circuit A-C or D-C? REF: 2.07
2-6. The power, in watts, of a D-C circuit may be determined by measuring _____ and _____ and then multiplying one by the other.	2-6. VOLTAGE and CURRENT volts times amperes equals watts REF: 2.07
2-7. Where on the meter scale is accuracy the greatest? _____	2-7. The UPPER TWO-THIRDS of the scale REF: 2.08
2-8. When selecting a meter for an unknown current or volts, always start with the _____ range available. *(highest/lowest)*	2-8. Use the HIGHEST range, and work down REF: 2.09

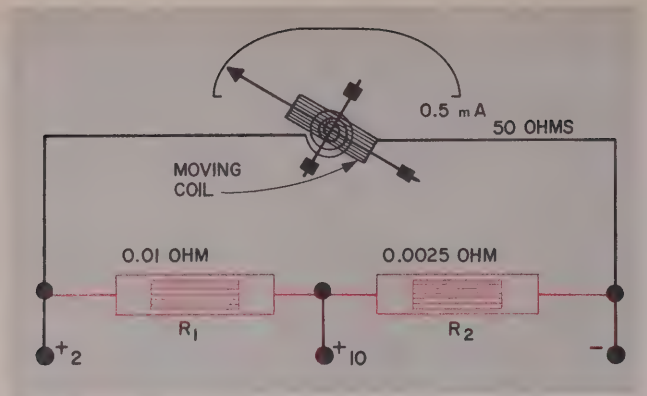


Fig. 2-4. Shunts in a two-scale ammeter circuit.

Accuracy Considerations

2.11 Most portable instruments are accurate within one percent of full-scale, but this high degree of accuracy can be canceled if good, commonsense rules for instrument use are not followed. Be sure the instrument is adequately shielded against outside magnetic fields. The most practical shield is air. For example, if an instrument is to be located on a control panel, the distance between the instrument and conductors carrying heavy currents must be adequate enough to permit instrument accuracy.

2.12 When more than one instrument is mounted on the panel, keep unshielded permanent-magnetic instruments 5 to 8 inches apart. This will reduce interaction of the fields of the instruments. Most high-grade portable instruments have a built-in magnetic shield, and they can be mounted next to each other without loss in accuracy.

2.13 Reading errors, up to 5 percent, may occur when permanent-magnet instruments are placed directly on a steel floor or bench. Flux leakage from the permanent magnet tends to cause a higher reading. Such errors may be avoided by placing the instruments on a nonmetallic box or support 4 to 5 inches high.

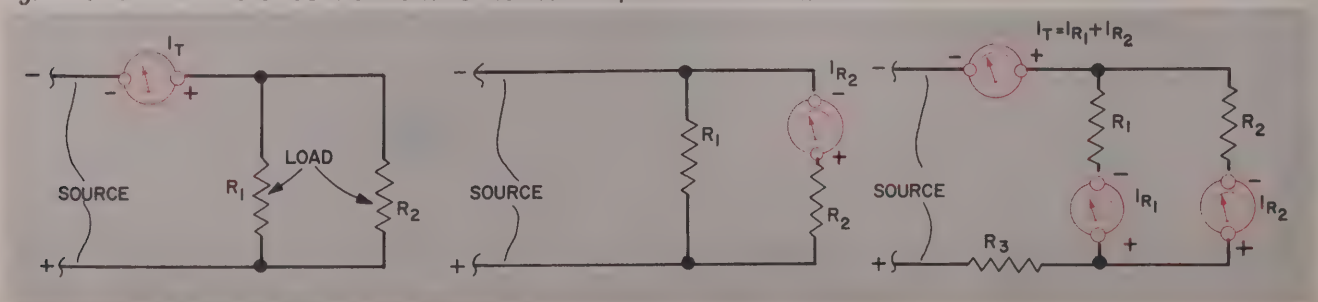
2.14 Temperature can change the accuracy of electrical instruments, but most manufacturers guarantee their instruments to operate within the limits of normal accuracy over a temperature range which varies ±10°C from normal operating temperature. The accepted normal operating temperature is about 25°C (77°F).

2.15 Reversing the leads of a D-C permanent magnet instrument will cause the pointer to swing in the opposite direction and strike the backstop in its efforts to record the current when a reading is taken. Simply reverse the leads when this happens. The direction of current flow in a moving-iron meter does not influence the pointer to any great degree. It still moves in the right direction to indicate the reading. Because the pointer may give a slightly different reading with the leads reversed, two readings should be taken; the second one taken with the leads reversed. The average of the two readings is the more accurate reading.

2.16 Figure 2-4 illustrates an arrangement of shunts for an ammeter with two scales. The terminals marked +2 and +10 can represent either binding posts or selector switch contacts. A set of values for resistance is shown. When the 2 ampere contact is used, the shunt consists of R_1 and R_2 in series. When the 10 ampere contact is used, R_2 acts as the shunt and R_1 is in series with the moving coil. A three-scale D-C ammeter contains a three-section shunt using the same principle of operation.

2.17 Any ammeter will act as a short circuit and probably be ruined if it is connected across a source or in parallel with a piece of equipment.

Fig. 2-5. D-C ammeter connections for series and parallel circuits.



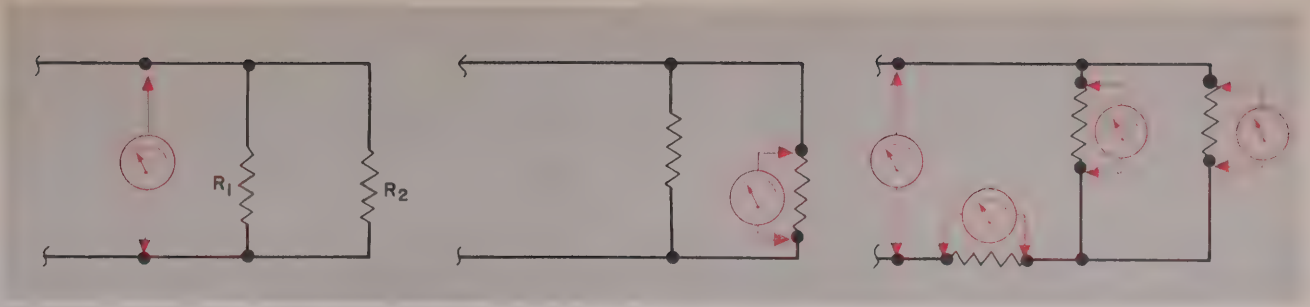


Fig. 2-6. D-C voltmeter connections for series and parallel circuits.

D-C ammeter connections for series and parallel circuits are illustrated in Fig. 2-5.

Use of D-C Voltmeters

2.18 A D-C voltmeter has a high resistance connected in series with the meter movement. Unlike an ammeter, a voltmeter is intended to be connected directly across the source of energy, or in PARALLEL with any equipment, to measure the voltage. Voltmeter circuit connections are illustrated in Fig. 2-6.

2.19 A voltmeter must be a high resistance instrument for two reasons:

1. Only a very small current can be permitted through the moving coil.

2. The insertion of the voltmeter in the circuit should not cause a drain on the source, which would reduce the emf being measured.

2.20 A voltmeter is actually an ammeter with a series resistor. When the resistance of the moving coil is increased by adding a HIGH resistance in SERIES with the coil, the resistor is called a MULTIPLIER. This extra resistance holds down the current to the value required for full-scale deflection when the full-scale voltage is applied to it. It is possible to use one meter to read many different voltage ranges if the correct resistances can be placed in the instrument with an arrangement for disconnecting one resistance and connecting another in series. Industrial meters, which do this by a switching arrangement, are available.

2.21 The conversion of a milliammeter or microammeter movement to a voltmeter is easy, both through calculation and in construction. You need only to calculate the series RESISTOR which will be connected to limit the CURRENT for a full-scale reading when the intended full-scale VOLTAGE is applied (Ohm's Law).

2.22 For example, if a meter is scaled 0 to 200 microamperes and you want a voltmeter reading up to 200 volts, the voltmeter must have a total resistance of 1,000,000 ohms. Using Ohm's Law

$$R = \frac{E}{I} = \frac{200}{0.0002} = 1{,}000{,}000 \text{ ohms}$$

2.23 This value is the total resistance of the moving coil plus the series resistor. Ordinarily, resistance of the moving coil is so small (50-100 ohms), that this last figure can be disregarded. In this case, a one megohm resistor connected in series with the moving coil makes the assembly a 200-volt voltmeter.

Voltmeter Sensitivity

2.24 The sensitivity of a meter movement determines the amount of current required to provide full-scale deflection.

2.25 The sensitivity of voltmeters is stated in ohms per volt. For example, if a 200-volt meter has 1,000,000 ohms resistance, the sensitivity of the instrument can be calculated as follows:

$$\frac{1{,}000{,}000}{200} = 5{,}000 \text{ ohms per volt}$$

2.26 A perfect voltmeter would measure the circuit without using any current. However, this is impossible, because a certain amount of current, no matter how small, is necessary to operate the meter. The best or most sensitive meters are those

which use as little current as possible. (The more resistance that can be placed in a meter and still have it read 1 volt, the less current drawn.)

D-C Voltmeter Connections

2.27 For connection of the instrument across the circuit to be tested, portable D-C voltmeters are provided with terminals. Several terminals may be provided, each marked with its function or measurement range. Test leads, lengths of flexible insulated wire, are also provided. Each lead has one end affixed to a connector for the terminal on the voltmeter and the other end contained in a metal circuit probe mounted in an insulated handle.

2.28 The distinction between positive and negative voltage is POLARITY. The proper connection polarity of a D-C voltage source is usually indicated at the terminals, with one terminal marked "positive" and the other marked "negative." In a D-C circuit, the terminal polarity of the equipment is the same as the terminal polarity of the supply source: plus-to-plus and minus-to-minus.

2.29 The terminals of a portable D-C voltmeter are either colored or marked to indicate the polarity. A red color or plus (+) mark identified a positive terminal. Black or minus (–) indicates a negative terminal. The negative terminal of a D-C voltmeter is connected through a test lead to the negative terminal (source or device) of the circuit. The other test lead is connected to the corresponding positive terminal of the meter and the circuit.

CAUTION: The polarity marking of the D-C voltmeter terminal must be the same as the polarity of the voltage being measured. If this practice is NOT followed, the scale pointer will move opposite to its normal direction and the instrument may be damaged.

Thermocouple Instruments

2.30 A thermocouple instrument is also used for electrical measurements. This type of instrument is frequently used when measuring current in milliamperes. It may also be used for voltage measurement at high frequencies. It can be used to measure A-C at any frequency from the 60 hertz used for plant power distribution, through the high frequency used in induction-heating applications. Because it can measure extremely high frequencies, the thermocouple instrument is sometimes called a radio-frequency (RF) instrument.

Construction

2.31 Basically a thermocouple instrument consists of a heater, a thermocouple, and a sensitive PM-MC mechanism. The actual current to be measured flows through a heater. The heat developed is proportional to the heater resistance and to the square of the effective value of the current (I^2R). One junction of the thermocouple is usually connected, electrically and mechanically, to the heater; the production of heat thus causes a rise in the temperature of the thermal junction, which results in the generation of a voltage at the thermocouple terminals. The sensitive D-C meter connected to the thermocouple terminals measures the terminal voltage of the thermocouple. The instrument scale is usually calibrated in direct proportion to the rise in temperature of the heater. The deflection of the pointer in thermocouple instruments is proportional to the square of the heater current (1^2). The scales are usually nonlinear: they are compressed at the lower end and expanded at the upper end.

2.32 The heaters and thermocouples for low-current milliammeters are usually enclosed in evacuated bulbs so that all of the heat will be transferred from the heater to the thermocouple.

Use these programed exercises to help check your learning progress.

2-9. How close to actual voltage should a 250 volt meter that has a 1% full-scale accuracy read on a 220 volt circuit? _____	2-9. It should be within 1% of 250 volts or ±2.5 volts. The range should be from 217.5 to 222.5 volts. REF: 2.11
2-10. List at least three factors that can affect accuracy of a meter. _____ _____ _____	2-10. 1. Meters TOO CLOSE together, or UNSHIELDED. 2. EXCESSIVE TEMPERATURES. 3. Placing meters on STEEL WORKPLACE. REF: 2.12, 2.13, 2.14, 2.15
2-11. How will a D-C ammeter act if it is connected in parallel with a voltage source? _____ _____	2-11. SHORT circuit, and probably will be ruined. REF: 2.17
2-12. How is a D-C voltmeter affected if it is connected in parallel with the voltage source? _____ _____	2-12. It is UNAFFECTED. This is the way it is intended to be used. REF: 2.18
2-13. What are two reasons for using high resistance in series with a voltmeter? _____ _____	2-13. 1. KEEP COIL CURRENT LOW. 2. PREVENT DRAIN ON VOLTAGE SOURCE. REF: 2.19
2-14. If you want to use a 150 microampere meter to measure 300 volts, how much resistance must be placed in series? _____ _____	2-14. $R = \frac{E}{I} = \frac{300}{0.000150}$ Resistance = 2,000,000 OHMS Use a 2 MEGOHM RESISTOR REF: 2.22
2-15. Other things being equal, the higher the resistance of a D-C voltmeter, the _____ its sensitivity will be.	2-15. HIGHER REF: 2.26
2-16. Wrong polarity connections can damage a PM-MC meter. Be certain red or + leads are connected to the _____ side of the line, and black or – leads to the _____ side.	2-16. Red or + to the POSITIVE side, black or – to the NEGATIVE side. REF: 2.29

Operating Principles of a Thermocouple

2.33 If the ends of two dissimilar metals are welded together and the resulting junction heated, a D-C voltage is developed across the two open ends. This is the principle of a thermocouple. The voltage developed depends on the type of material the wires are made from and the difference in temperature between the heated junction and the open ends.

2.34 A basic sketch of a thermocouple-operated instrument is shown in Fig. 2-7. In this type of instrument, the junction is electrically heated by the flow of current through a heater element. It does not matter whether the current is A-C or D-C because the heating effect is independent of current direction. The maximum current that can be measured depends on the current rating of the heater, the heat that the thermocouple can stand without being damaged, and the current rating of the meter used with the thermocouple.

2.35 The heat produced by the flow of current through the heater strip, being proportional to the square of the heating current ($P = I^2 R$), causes the movement of the meter element. The element is connected across the terminals of the heater strip. A more detailed thermocouple instrument is illustrated in Fig. 2-8.

2.36 A thermocouple may be built into the instrument case or it may be mounted externally. The practice is similar to that practice followed in locating ammeter shunts – the thermocouple and heater are internally mounted for low current ratings, and externally mounted for high current ratings.

2.37 The function of the D-C mechanism in a thermocouple instrument is the measurement of the D-C potential developed by the thermocouple. It is designed to provide full-scale deflection with full rated current through the thermocouple.

2.38 The meter used with a thermocouple has a low resistance to match the low resistance of the thermocouple, as it must deflect full-scale when full rated current flows through the heater.

2.39 If the thermocouple is burned out by excessive current through the heater strip, the thermocouple may be replaced and the meter recalibrated by means of a calibrated variable resistor, where the calibration itself is known.

Principles of Thermal Metering

2.40 The basic principle on which a THERMAL type meter operates is the direct conversion of electrical energy into heat. Components used in the measuring element of the meter consist of non-inductive resistors (heaters), heat storage enclosures, matched bimetallic coils, and, when necessary, small current transformers and potential transformers. The manner in which these components function to measure electrical values in a thermal meter are:

1. Heat is converted into a heat difference.

Fig. 2-7. Functional components of a thermocouple instrument.

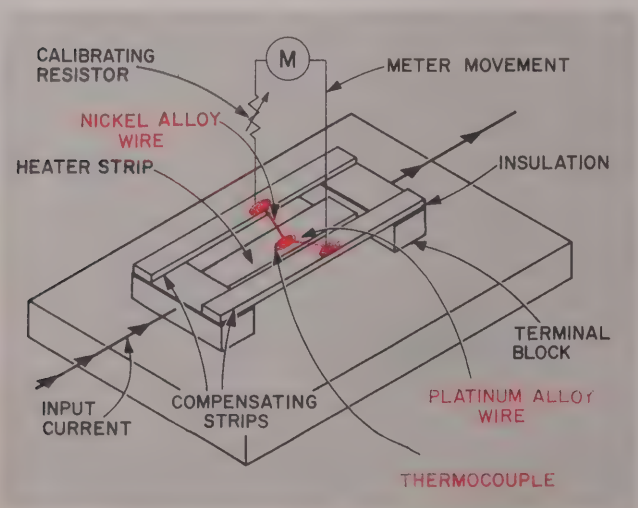
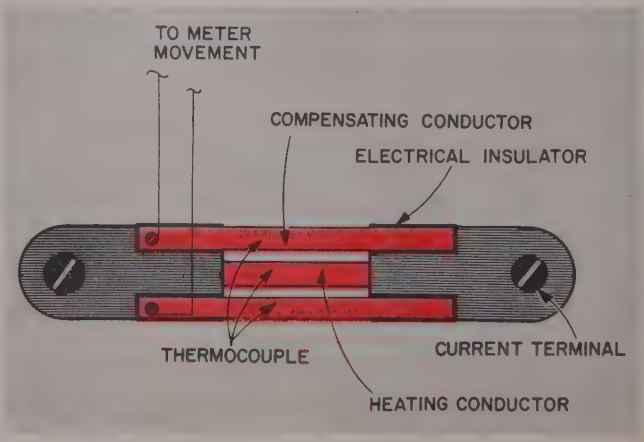


Fig. 2-8. Thermocouple instrument for low current ratings.



2. Heat difference is converted into a temperature difference.

3. The temperature difference is converted into pointer deflection.

This type of current-measuring instrument is sometimes called a "hot-wire" meter.

2.41 When current flows through a wire, one of the most noticeable effects is the heat generated in the wire. Less noticeable is the fact that this heating causes a slight increase in the length of the wire. It is also possible to measure the value of the current in terms of the change in the length of the wire, and some ammeters have been designed using this principle of operation, but they are not in common use.

2.42 A bimetallic, temperature-sensitive strip that will bend when heat is applied, as illustrated in Fig. 2-9(A), is wound into a coil with a shaft and pointer attached. When current flows through the heater, heat is produced proportional to the current squared times the resistance (I^2R). This causes an expansion of the bimetallic coil and a pointer deflection directly proportional to the current value squared (I^2). This single bimetallic coil will give an indication proportional to the square of the current, but it is sensitive enough to also respond to ambient temperature changes.

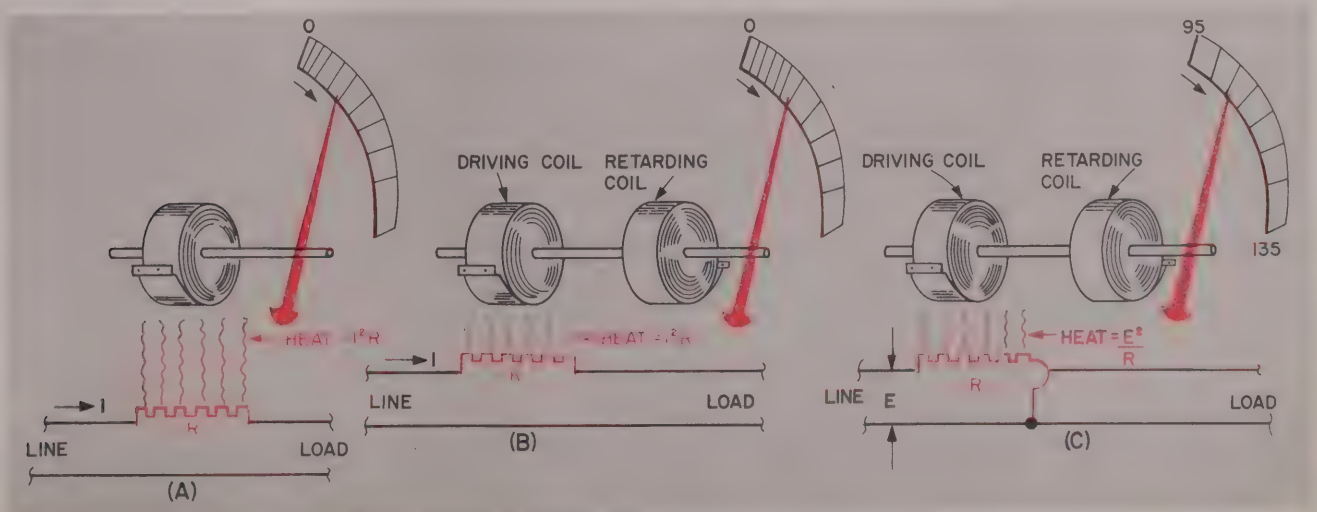
2.43 To eliminate the response from ambient temperature changes, a second bimetallic coil is carefully matched with the first and put on the shaft so as to turn in the opposite direction, as illustrated in Fig. 2-9(B). Then, when the temperature changes, one coil tries to move the pointer up and the second tries to move the pointer down. The end result is that the pointer is not influenced by ambient temperature changes and is, therefore, more accurate.

2.44 The bimetallic coils are contained in separate enclosures in the ammeter. When current is passed through the meter, heat is developed in one enclosure causing its ambient temperature to rise above the ambient temperature in the other enclosure. Responding to this difference, the bimetallic coils produce a more accurate deflection of the pointer, which is proportional to the square of the current.

2.45 A thermal voltmeter utilizes the same components and principles of operation as the ammeter except that the heater is connected across the line, as illustrated in Fig. 2-9(C). The current passing through it is proportional to the line voltage. With the heater connected across the line, the current circulating through the heater develops heat within the enclosure proportional to E^2/R, which causes the temperature of the enclosure to rise above that of the other. This temperature difference, through the bimetallic coils, produces a deflection of the pointer which is proportional to the voltage.

2.46 The basic circuitry of the thermal ammeter can be applied to measure kilowatts (KW),

Fig. 2-9. Thermal Ammeter Schematics.



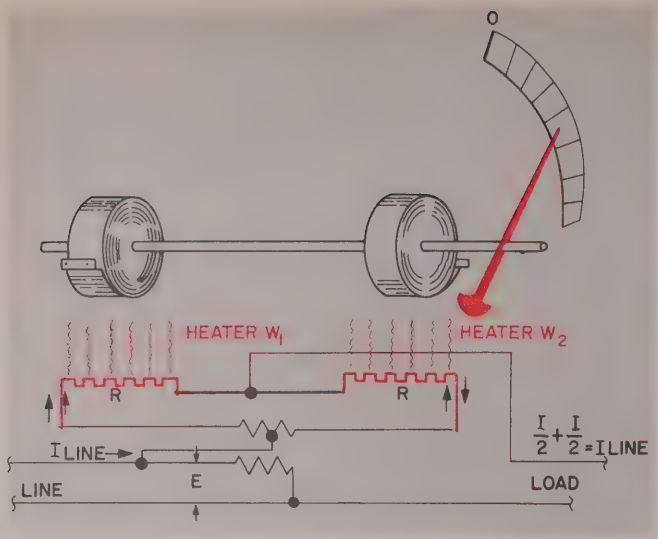


Fig. 2-10. Schematic of a thermal wattmeter.

kilovolt-amperes-reactive (KVAR), and kilovolt-amperes (KVA).

2.47 The basic circuit for a thermal-type meter designed to measure watts is illustrated in Fig. 2-10. The primary of a small potential transformer is connected across the line and the secondary is connected in series with the two noninductive heaters of equal resistance. The heaters are contained in separate enclosures. When both the current and voltage are applied, a circulating current proportional to the line voltage passes through the heaters. A second input of current, proportional to the line current, is introduced through the mid-tap in the potential transformer secondary, and it is divided so that one-half flows through each heater.

NOTE: The components of the current are additive in the rear heater but the current is subtractive in the front heater. Because temperature rise in each enclosure is proportional to the heat input, the temperature difference between the two enclosures corresponds to the difference in the two values of heat input, or, more simply, the result corresponds to the watts being expended. This temperature difference of the bimetallic coils produces a deflection of the pointer on the scale.

2.48 The principle of the thermal watt or kilowatt meter can be applied to the measurement of all single-phase and polyphase circuits. Although the circuit of the two-wire thermal meter has only one heater associated with each bimetallic coil, two, three, four, or six heaters are utilized in polyphase meters. Because polyphase circuits consist of two or more two-wire single-phase circuits, the heat inputs of the two-wire circuits can be added together and the resultant temperature difference measured with one pair of bimetallic coils.

Measuring KVAR with a Thermal Meter

2.49 Thermal meters to measure KVAR are usually provided with a selector switch and a two-position plug that provides two tap positions. The one position is for power measurement at unity power-factor, or the watt-demand measurement.

2.50 The "0" or unity position is provided for convenience in testing because, with the plug in this position, the meter may be calibrated as a KW meter. After the meter is calibrated for watts, it is only necessary to move the switch plug to the KVAR position to measure KVAR demand.

2.51 Thermal kilovolt-ampere meters also utilize the same basic components and principles of operation as the KW thermal meter.

2.52 In today's complex industrial plant, power measurements can help the maintenance electrician solve everyday problems and realize important economies in maintaining the electrical system. Thermally averaged meters for the measurement of Watts, VARs, and KVARs are quite useful in industrial plant electrical applications. The meter principles explained in this lesson can be applied to other functions in your electrical maintenance responsibilities.

2-17. Heating the welded junction of two dissimilar metals will cause a _____ voltage to be developed across the open ends.	2-17. D-C voltage REF: 2.33
2-18. Since the heating effect of the current being measured is not dependent on direction of current flow, a thermocouple instrument can be used to measure _____. *(D-C only/A-C and D-C)*	2-18. A-C and D-C REF: 2.34
2-19. Heat output is proportional to the square of the current through the heater strip in a thermocouple instrument. If the current is doubled, the heat will be increased by _____ times.	2-19. FOUR times. $2^2 = 2 \times 2 = 4$ REF: 2.35
2-20. A thermocouple and heater are usually mounted _____ *(externally/internally)* for low current meters and _____ *(externally/internally)* for high current meters.	2-20. INTERNALLY EXTERNALLY REF: 2.36
2-21. How does a thermal meter differ from a thermocouple meter? _____ _____	2-21. The thermal meter DOES NOT GENERATE A VOLTAGE, but converts HEAT to MECHANICAL deflection of the pointer. REF: 2.40
2-22. What prevents the bimetallic element of a thermal meter from being affected by the temperature of the room where it is being used? _____ _____	2-22. TWO MATCHED BIMETALLIC elements are mounted in OPPOSITE directions on the SAME SHAFT REF: 2.43
2-23. In a thermal voltmeter, the heater is connected in _____ *(series/parallel)* with the circuit being measured.	2-23. In PARALLEL (across the line) REF: 2.45
2-24. A thermal wattmeter consists of two separate bimetallic elements, one to measure _____ and the other to measure _____.	2-24. One measures CURRENT, the other measures VOLTAGE REF: 2.47

ACCURACY – A value that expresses the maximum deviation from the true value of a measured quantity, usually expressed as a percentage of the full-scale rating of the instrument.

COMPENSATED INSTRUMENT – An instrument so constructed that correction is made automatically for certain types of errors. (For example, temperature errors.)

CONCENTRIC-SCALE INSTRUMENT – An instrument which uses a scale that is a large part of a complete circle, which is concentric with the shaft of the moving system.

CONSTANTAN – A special alloy of nickel and copper which has a negligible temperature coefficient of resistance.

DAMPING VANE – A metal vane used in the instrument damping system. In a magnetic system, the damping vane passes through the flux of a permanent magnet; in an air system, the damping vane operates in a closed chamber.

MIRROR SCALE – A scale that has a mirror so located that the reflection of a knife-edge pointer is directly in line with the pointer when the viewpoint is proper to read the instrument, thus avoiding parallax error.

RANGE – The limits between which accurate measurements can be made, usually expressed in terms of the calibrated points at the ends of the scale. Sometimes the instrument range is expressed as the maximum calibrated rating of the instrument.

SHUNT – A special resistance element designed to be connected in parallel with an instrument to extend its readable current range beyond the value for which the mechanism of the instrument is already designed.

STRAY FIELD – Any magnetic field not needed by the instrument.

SWAMPING RESISTOR – A special resistor made of material with a low temperature coefficient of resistance, which is connected in series with an instrument coil to minimize the effect of ambient temperature variations.

TEMPERATURE COEFFICIENT OF RESISTANCE – The change in resistivity of a conductor for each unit change in temperature.

TEMPERATURE-COMPENSATED INSTRUMENT – An instrument so constructed as to be substantially unaffected by temperature changes.

THERMOELECTRIC EFFECT – The electromotive force developed when heat is applied at the point of contact between any two dissimilar metals.

THERMOCOUPLE – A device which consists of a pair of dissimilar metallic conductors so joined as to produce a thermoelectric effect when heated.

THERMOJUNCTION – The point at which dissimilar metals are joined in a thermocouple. This is where heat is applied to produce the thermoelectric effect.

VAR (Volt-Ampere-Reactive) – The unit of reactive power; the product of current and voltage and the sine of the phase angle, sometimes designated reactive volt-ampere.

SELF-CHECK QUIZ

2-1. How should a D-C ammeter be connected in a circuit being tested?

a. In series with the shunt, in parallel with the circuit.
b. In series with the circuit, in parallel with the shunt.
c. In series with both the shunt and the circuit.
d. In parallel with both the shunt and the circuit.

2-2. Where on the scale is an electrical meter likely to be most accurate?

a. Top of the scale
b. Upper two-thirds of the scale
c. Lower third of the scale
d. Bottom of the scale

2-3. When operating a meter, to measure an unknown current or voltage, it is best to

a. start with the highest range and work down
b. start with the lowest range and work up
c. select an estimated mid-range
d. use the trial and error method

2-4. Which of the following is likely to affect the accuracy of an electrical meter?

a. Bringing the voltage up too fast
b. Using it on too low a voltage
c. Working with it on a steel work-bench
d. All of the above

2-5. How should a D-C voltmeter be connected in a circuit being tested?

a. In series with the multiplier, in parallel with the circuit.
b. In series with the circuit, in parallel with the multiplier
c. In series with both the multiplier and the circuit
d. In parallel with both the multiplier and the circuit.

2-6. When connecting a PM-MC meter in a circuit, be sure the leads are connected in which of the following manners?

a. Red to black
b. Positive to negative
c. Red to negative, black to positive
d. Red to positive, black to negative

2-7. A thermocouple instrument can be used on

a. A-C circuits only
b. D-C circuits only
c. Polyphase circuits only
d. A-C or D-C circuits

2-8. If the current increases by three times through a thermocouple heater strip, the heat output will increase by

a. 3 times
b. 6 times
c. 9 times
d. 12 times

2-9. A thermal meter differs from a thermocouple meter in that a thermal meter

a. produces a small D-C current
b. has heaters
c. can be used for current or voltage measurement
d. produces pointer deflection directly by heat

2-10. What values are measured by the two separate bimetallic elements of a thermal wattmeter?

a. Heater temperature and ambient temperature
b. Voltage and current values
c. KW and KVAR
d. Kilowatts and KVA

ANSWERS TO SELF-CHECK QUIZ

2-1. b. In series with the circuit, in parallel with the shunt. REF: 2.02, 2.04.

2-2. b. Upper two-thirds of the scale. REF: 2.08.

2-3. a. Start with the highest range and work down. REF: 2.09.

2-4. c. Working with it on a steel workbench. REF: 2.13.

2-5. a. In series with the multiplier, in parallel with the circuit. REF: 2.18, 2.20.

2-6. d. Red to positive, black to negative. REF: 2.29.

2-7. d. A-C or D-C circuits. REF: 2.34.

2-8. c. 9 times. REF: 2.35.

2-9. d. Produces pointer deflection directly by heat. REF: 2.40.

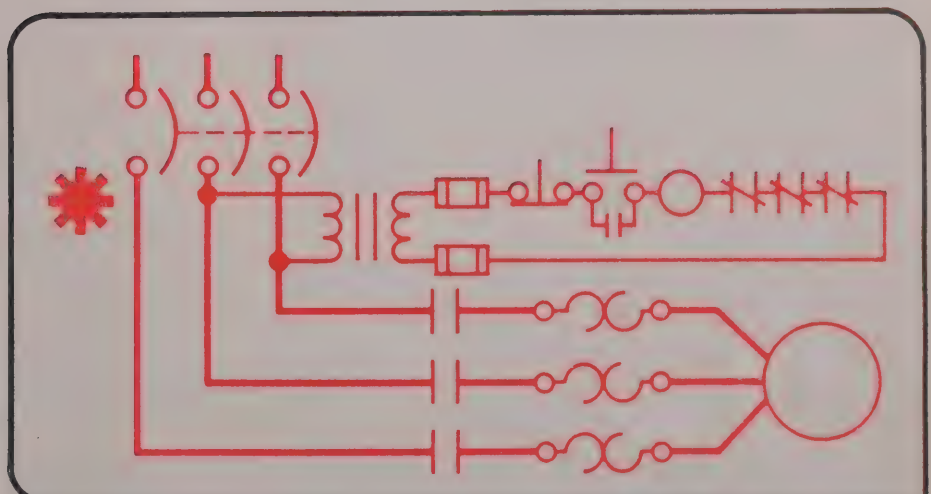
2-10. b. Voltage and current values. REF: 2.47.

LESSON THREE

RESISTANCE AND INSULATION MEASUREMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Three — Resistance and Insulation Measurements

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Lesson Three — Resistance and Insulation Measurements

Preface

There are two general methods of measuring resistance values: (1) directly, by the use of an ohmmeter or megohmmeter, and (2) indirectly, by use of a wheatstone bridge, or an ammeter and voltmeter, and then applying Ohm's Law. Both methods require a source of current, though the method applied depends on the range of measurement and the required accuracy.

The ohmmeter is used to measure resistance and check the continuity of electrical circuits and devices. Its range usually extends to only a few megohms. The megohmmeter is used for measuring insulation resistance of wires, as between the wire and the outer surface of its insulation, and the insulation resistance of cables and insulators. The range of a megohmmeter may extend to more than 1,000 megohms.

The principles and methods of resistance measuring, which are conducted on a day-to-day basis in an industrial plant, are explained in this lesson.

Ohmmeter Operating Principles

3.01 An ohmmeter is used to measure resistance and uses a D'Arsonval (PM-MC) movement. An ohmmeter's movement is usually very sensitive, and it requires only a small amount of current for full-scale deflection.

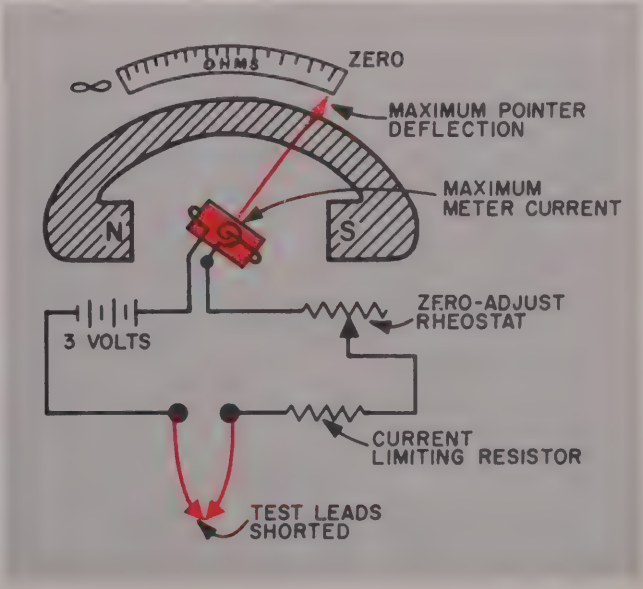
3.02 An ohmmeter consists of a D-C milli-ammeter type movement with the following added features:

1. A D-C source of potential (usually a small battery).

2. One or more resistors (one of which is variable).

3.03 The simple ohmmeter circuit illustrated in Fig. 3-1 shows the basic circuit of the ohmmeter, which consists of a meter movement, a current limiting resistor, a zero adjustment resistor, a meter mechanism for the meter movement, and a battery. Full-scale deflection is obtained, when external resistance is being measured, with the meter leads shorted together. Therefore, the current limiting

Fig. 3-1. Ohmmeter circuit with shorted test leads.



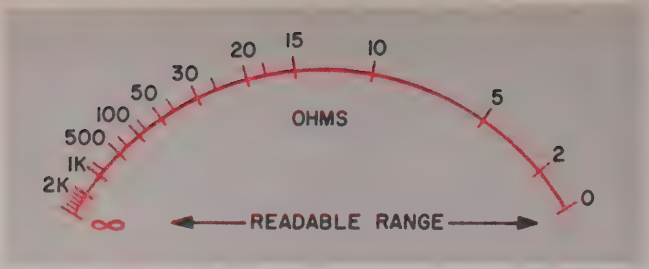


Fig. 3-2. Single range ohmmeter scale.

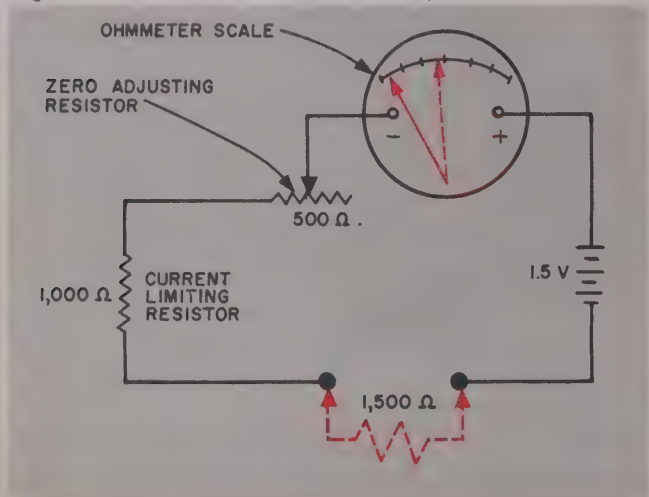
resistor of the meter circuit must limit the current to the value for which the movement is rated.

3.04 The pointer deflection of the ohmmeter is controlled by the amount of battery current passing through the moving coil. Before measuring the unknown resistance of a resistor or electrical circuit, the test leads of the ohmmeter are shorted together, as illustrated in Fig. 3-1, to set the meter pointer on zero.

Ohmmeter Calibration

3.05 An ohmmeter is calibrated by shorting the leads together and setting the pointer to zero by means of the variable resistor as follows: First, set the ohmmeter to the selected range, because the zero setting usually varies for different ranges. Short the leads together. (While the leads are shorted together, current flow is maximum and the pointer is deflected full-scale.) Use the variable resistor to bring the pointer to rest exactly on the zero graduation. This indicates ZERO RESISTANCE between the shorted test leads.

Fig. 3-3. Ohmmeter circuit example.



NOTE – The zero readings of ohmmeters are usually on the right-hand side of the scale, whereas the zero readings for ammeters and voltmeters are generally on the left-hand side of the scale.

3.06 The scale of an ohmmeter, Fig. 3-2, is known as a reversed scale because the zero graduation is on the right, which corresponds to full-scale deflection. That is, maximum deflection of the meter indicates zero ohms of resistance. The scale is calibrated relative to battery current and total resistance – total resistance being the resistance of the meter plus the resistance being measured.

3.07 For example, use a basic ohmmeter circuit, as illustrated in Fig. 3-3, then add a resistance (dashed lines in the illustration) equal to that of the meter across the terminals. Then determine what value the meter will indicate on the scale. To do this, first calculate the current through the meter. Let's say the battery is 1.5 volts and the total resistance is 3000 ohms. Using Ohm's Law, the answer is 500 microamps. This is half the full-scale current, so the meter will register half-scale deflection. This point is marked on the scale in ohms rather than in amperes. The other points on the scale are also marked in a similar manner.

3.08 Note that the graduations on the ohmmeter scale are not evenly spaced, Fig. 3-2, and that the pointer deflection becomes less as the resistance increases. This occurs because the greater the resistance is, the smaller the value of current flow for any given voltage. This is a simple application of Ohm's Law.

CAUTION – NEVER use an ohmmeter to measure resistance of an energized circuit. The internal circuit is designed to carry only the current produced by its own battery. Its voltage is usually between 1.5 and 9 volts. Any voltage from an external source will likely be larger than this value and will damage either the meter coil, the pointer or both, usually beyond repair.

Use of the Ohmmeter

3.09 A multirange ohmmeter with the zero adjust and range selector is illustrated in Fig. 3-4. Each time the meter is to be used for reading ohms, and each time it is switched to a new range,

Fig. 3-4. A multirange ohmmeter.

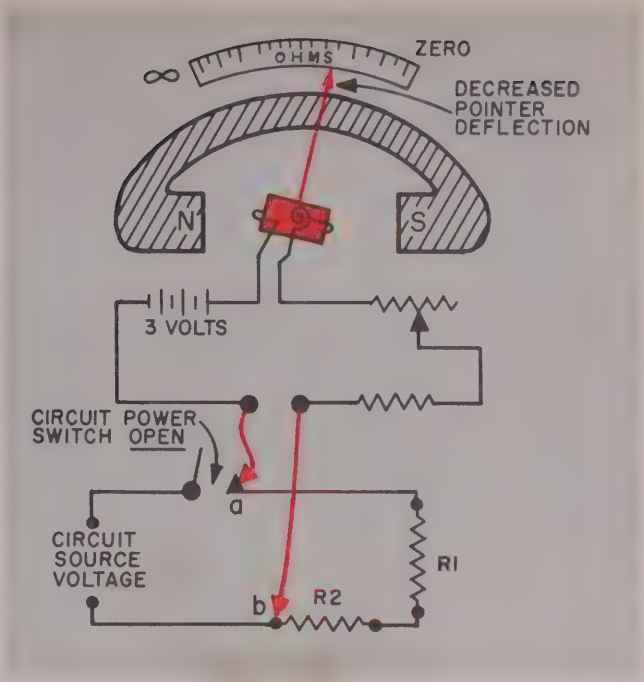


Fig. 3-5. Ohmmeter circuit for measuring resistance.

short the test probes together and zero the pointer with the zero ohms adjustment control (the variable resistor or potentiometer).

3.10 After the ohmmeter is adjusted for a zero-ohms reading, it is ready to be connected into a de-energized circuit to measure resistance. A typical ohmmeter circuit arrangement is illustrated in Fig. 3-5.

3.11 The test leads of the ohmmeter are connected across the circuit to be measured. This causes the current produced by the meter's battery to flow through the circuit being tested. Assume that the meter test leads are connected at points A and B of Fig. 3-5. The amount of current that flows through the meter coil will depend on the resistance of the meter. Because the resistance of the meter has been adjusted, the amount of coil movement now depends solely on the resistance of R1 and R2. The resistance of R1 and R2 raises the total series resistance in the circuit, decreases the current, and thus decreases the pointer deflection away from zero. The pointer now comes to rest at a scale figure that indicates the combined resistance of R1 and R2. If R1 and R2 were replaced with a resistor having a larger ohmic value, the current flow in the moving coil of the meter would be decreased still more. The deflection would also be further decreased, and the scale indication would read a still higher circuit resistance. Movement of the moving coil is proportional to the amount of current flow. The scale reading of the meter, in ohms, is inversely proportional to the current flow in the moving coil.

Ohmmeter Multiplication Features

3.12 The amount of circuit resistance to be measured may vary over a wide range. In some cases the amount may be only a few ohms, and in other cases, the amount may be as great as one million ohms. To enable the meter to measure values with the least error, multiplication features are incorporated. For example, an ohmmeter may have four test lead jacks, marked as follows – Common, R x 1, R x 10, and R x 100. The jack marked COMMON is connected internally through the battery to one side of the moving coil of the ohmmeter. The jacks marked R x 1, R x 10, and R x 100 are connected to three different size resistors located within the ohmmeter. This circuit is illustrated in Fig. 3-6.

3.13 Ohmmeters may also be equipped with a selector switch for selecting the multiplier scale desired, so that only two test lead jacks are necessary, usually marked COMMON and OHMS. Other meters have a separate jack for each range.

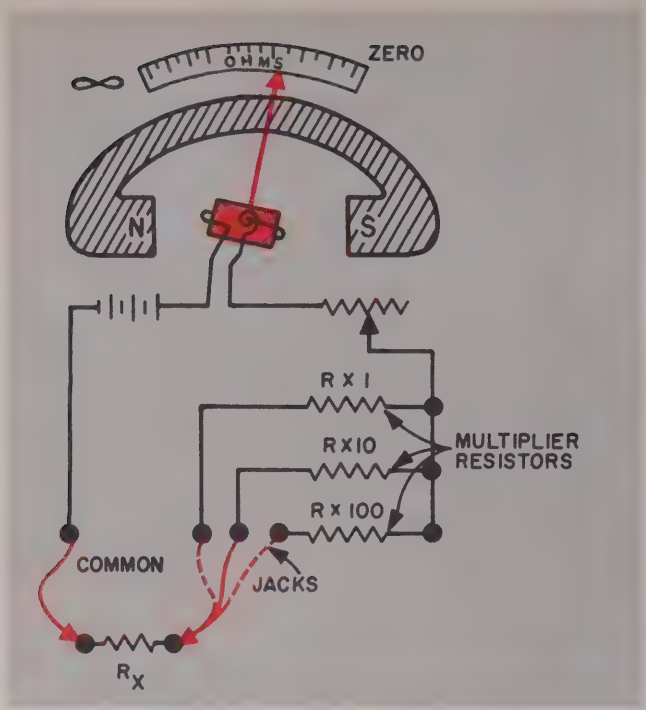


Fig. 3-6. Multiple range ohmmeter circuit for measuring resistance.

The range to be used in measuring a particular unknown resistance depends on the approximate ohmic value of the unknown resistance. For example, assume the ohmmeter is calibrated in divisions from zero to 1,000. If R_X is greater than 1,000 ohms and the R x 1 range is being used, the ohmmeter cannot properly measure it and the pointer just barely deflects. The combined series resistance of resistor R x 1 and R_X is too great to allow sufficient battery current to flow to deflect the pointer very much away from infinity (∞). The test lead should be plugged into the next range, R x 10. With this done, the pointer deflects to a readable value; for example, 375 ohms. This indicates that R_X has 375 ohms times 10, or 3,750 ohms. The change in range increased pointer deflection because resistor R x 10 has only one-tenth the resistance of the resistor R x 1. Selecting the smaller series resistance thus permitted a sufficient amount of battery current to cause a readable pointer deflection. If the R x 100 range were used to measure the same 3,750 ohm resistor, the pointer would deflect still further, to the 37.5 ohm position. This increased deflection would occur because resistor R x 100 has only one-tenth the resistance of resistor R x 10.

3.14 It always takes the same amount of current to deflect the pointer to a certain position on the scale (midscale position, for example), regardless of the multiplication factor being used. Because the multiplier resistors are of different values, it is ALWAYS necessary to zero adjust the meter for each multiplication factor when you select it. Try to select the multiplication factor that results in the pointer coming to rest as near as possible to the midpoint of the scale. This will enable you to read the resistance more accurately because the scale readings are more easily interpreted at, or near, midpoint.

Use these programed exercises to help check your learning progress.

3-1. The pointer deflection of an ohmmeter is controlled by the amount of _____ _____ that passes through the moving coil.	3-1. BATTERY CURRENT REF: 3.04
3-2. An ohmmeter is calibrated on the job by shorting the leads together and adjusting the pointer to _____.	3-2. ZERO REF: 3.05
3-3. The zero graduation of an ohmmeter scale is located on the _____ _____ side of the scale.	3-3. RIGHT HAND REF: 3.06
3-4. You should NEVER use an ohmmeter to measure resistance of any circuit that is _____.	3-4. ENERGIZED REF: 3.08
3-5. The zero adjustment of an ohmmeter should be made each time it is switched to a _____ _____.	3-5. DIFFERENT RANGE REF: 3.09
3-6. With respect to the amount of current flow in an ohmmeter, the movement of the moving coil is _____.	3-6. PROPORTIONAL REF: 3.11
3-7. The jacks on an ohmmeter, marked Rx1, Rx10, and Rx100, are internally connected to three different size _____.	3-7. RESISTORS REF: 3.12
3-8. Ohmmeter readings can be more accurately read on the meter scale at or near the _____.	3-8. MIDPOINT REF: 3.14

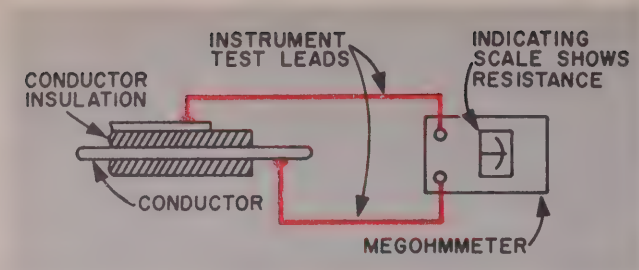


Fig. 3-7. Connections for measuring insulation resistance.

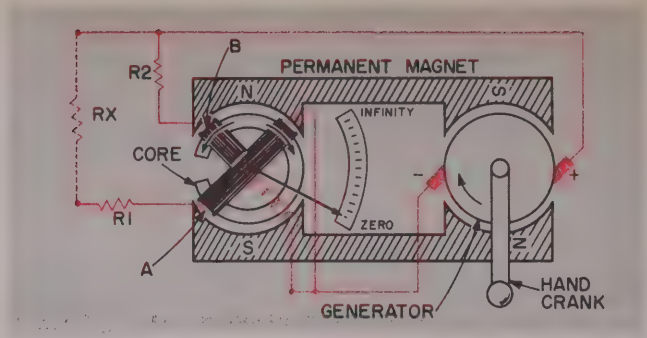


Fig. 3-9. Megohmmeter circuitry.

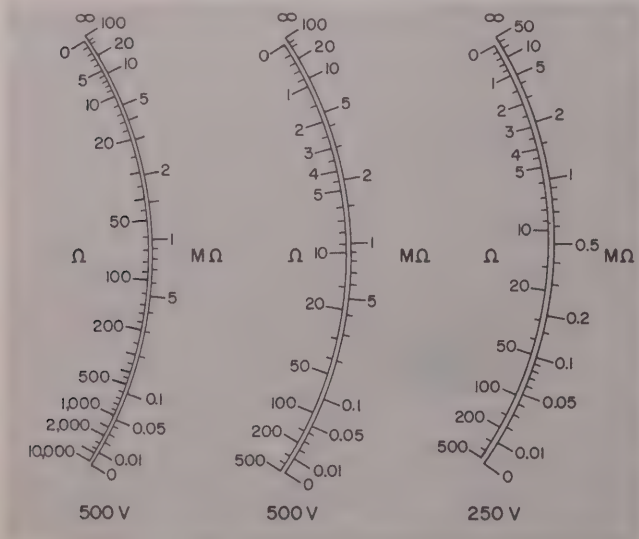
The Megohmmeter

3.15 An ordinary ohmmeter cannot be used for measuring resistance of many millions of ohms, such as resistance of conductor insulation. To properly test for "insulation breakdown," it is necessary to use a much higher potential than is furnished by an ohmmeter's battery. This potential is placed between the conductor and the outside surface of the insulation, as illustrated in Fig. 3-7.

3.16 A megohmmeter is used for these tests. A megohmmeter is frequently called a Megger.® It is a portable instrument consisting of (1) a hand-driven D-C generator, which supplies the necessary voltages for taking the measurement, and (2) the instrument mechanism, which indicates the value of the resistance being measured. There are no restraining springs attached to the indicating device in the megger. Therefore, when the generator is not operated, the pointer floats freely, and it may come to rest at any position on the scale. Typical scales are illustrated in Fig. 3-8.

® Megger is a trademark of the James Biddle Co.

Fig. 3-8. Typical megohmmeter scales.



3.17 The megohmmeter is expressly designed to measure very high resistances, and it derives its name from the fact that these resistances are in the "megohm" range. (The term mega means million.)

3.18 The meter used in the megohmmeter has two coils, as illustrated in Fig. 3-9, mounted over a gapped core. The coils are wound on a light frame, similar to that of the D'Arsonval movement, and they rotate around the core, which remains stationary. The current for the coils is supplied by the hand-driven generator. The hand-driven generator that supplies the testing voltage consists of a permanent rotor and a wound stator. The A-C voltage generated is rectified by a static rectifier, and the resulting D-C voltage is applied to the insulation under test. Little effort is required to turn the generator.

3.19 When the terminals are open, current flow is from the generator through B and R_2, which are in series with the generator. Because terminals are open-circuited, no current flows through coil A, to oppose its movement, and coil B swings counter-clockwise to a position over the gap in the core. In this position the pointer indicates infinity (∞).

3.20 With the terminals shorted together, a larger current flows through one coil (A) than through the other coil (B) and the greater force in coil (A) moves the pointer clockwise to the zero position on the scale. Current limiting resistor R_1 prevents damage to the meter in this short-circuited condition.

3.21 If a resistance is connected across the terminals, current flows through coil A, R_1 and the unknown resistance R_X. This current attempts to move coil A clockwise, but the opposing force created by current through coil B tries to move it

counterclockwise. The final position of the coils is determined by the magnitude of the current through R_X, and the coils stop at a point where the forces tending to move them are in balance. The pointer then indicates the value of the unknown resistance on the scale. No springs are used in the movement because the opposing forces in coils A and B balance the pointer when a reading is being taken. Having no springs to hinder its movement, the pointer floats freely back and forth across the scale when the instrument is not in operation.

3.22 If the test leads are not connected, no current flows in coil A. However, current flows through coil B, and deflects the pointer to infinity, which indicates a resistance too large to measure. When a resistance such as R_X is connected between the test leads, current also flows in coil A, tending to move the pointer clockwise. At the same time, coil B again tends to move the pointer counterclockwise. Therefore, the moving element, composed of both of the coils and the pointer, comes to rest at a position where the two forces are balanced. This position depends upon the value of the external resistance, which controls the relative magnitude of current in coil B. Because changes in voltage affect both coil A and coil B in the same proportion, the position of the moving system is independent of the voltage. If the test leads are short-circuited, the pointer rests at zero because the current in A is relatively large. The instrument will not be damaged under these circumstances, because the current is limited by R_1. A typical hand-driven megohmmeter is illustrated in Fig. 3-10.

3.23 Megohmmeters can be obtained in different voltage ranges, from 500 to 2,500 volts. The higher the resistance range to be measured, the higher the voltage required to actuate the movement for a reading. A friction clutch is used to restrict the generator's output to its rated voltage. In operation, the clutch is designed to slip if cranked over a certain rate of speed, thus keeping the output to a safe value.

3.24 The use of a megohmmeter to test insulation resistance is non-destructive: That is, although a very high voltage exists at the terminals, the testing does not cause deterioration of the insulation.

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Fig. 3-10. A heavy-duty multirange megohmmeter.

3.25 These instruments are ideal for detecting and diagnosing faulty insulation before damage occurs. Their applications include tests on motors, wiring, lighting circuits, control equipment, switchboards, appliances, electronic equipment, meters and relays, industrial heating units, signaling equipment, aircraft wiring and equipment – nearly everything electrical.

3.26 There are other types of megohmmeters, which are used in the same manner, except that the voltage is supplied by batteries located within the instrument. This type does not require a generator but insulation resistance can be measured in the same way. The handcrank type illustrated in Fig. 3-10 is manufactured in several sizes as required to fill the individual plant's requirements for accuracy, voltage, and compactness.

3.27 Rules to follow when making megohmmeter tests are:

1. Make sure the EQUIPMENT to be tested IS NOT ENERGIZED. It should be disconnected from all other equipment and circuits.

2. Know what equipment is included in your test. The megohmmeter measures whatever resistance is between its terminals.

3. Be sure to discharge capacitors that may be charged – both before and after the test – particularly with large equipment.

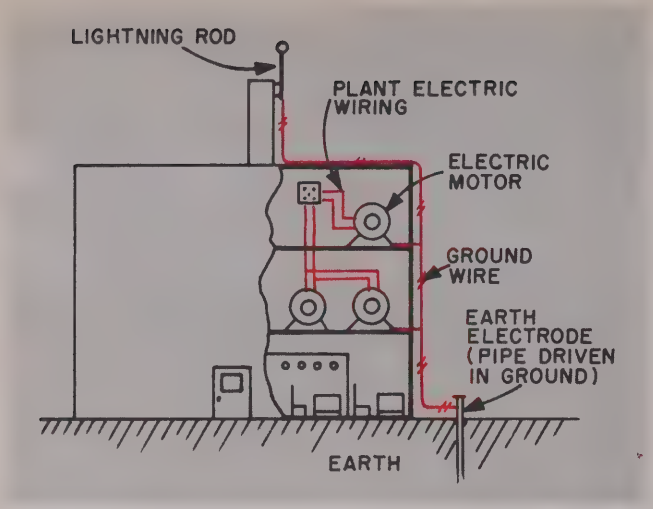


Fig. 3-11. A simple ground system for an industrial building.

WARNING: The megohmmeter is capable of administering severe shock voltages. Do not hold the bare contact part of the test leads while the megohmmeter is being cranked.

Understanding Insulation Resistance

3.28 Every electric wire used in an industrial plant whether it is in a motor, generator, cable, switch, transformer, or other electrical device is carefully covered with some form of electrical insulation. The wire itself is usually copper or aluminum, which are good conductors of the electric current that powers the electrical equipment. The insulation must be just the opposite from a conductor. It should resist current and keep the current in its proper path through the conductor.

3.29 To understand insulation testing you really do not have to go into the mathematics of electricity. Ohm's Law and common sense tell us that the more voltage we have, the more current there will be. Also, the lower the resistance of the wire, the more current for the same voltage.

3.30 Good insulation has high resistance; and that resistance value can become higher or lower, depending upon such factors as the ambient temperature and the moisture content of the insulation (resistance decreases with an increase in temperature or moisture). Through the use of records, such as the resistance test record shown in Table 3-1 on the last page of this lesson, you can be made aware of the insulation condition from values that are only relative.

Proper Grounding — and Its Importance

3.31 In an industrial plant or other facility that requires a grounding system, all of the following must be carefully considered:

Proper grounding of metallic enclosures and supporting structures.

Protection against static electricity from friction.

Good grounds for electric process control and communication circuits.

Protection against induced lightning voltages.

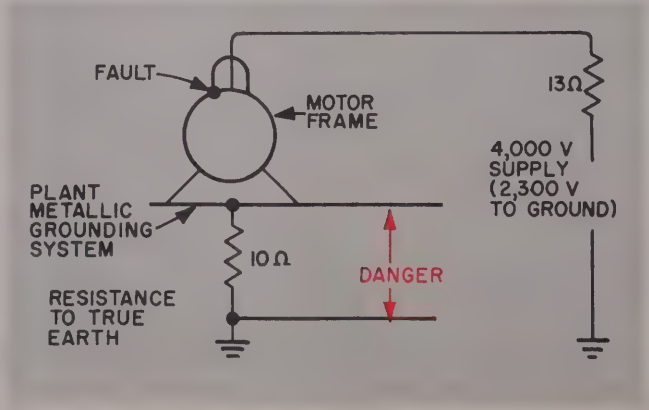
Protection against damage from direct lightning strikes.

Limitation throughout the entire electrical system of any voltage to ground.

3.32 A simple and somewhat misleading conception of a "ground" for an electrical system is a section of iron pipe driven into the earth with a wire conductor connected from the pipe to the electrical circuit, as illustrated in Fig. 3-11. This may not be enough of a suitable low resistance path for electric current to protect personnel and equipment.

3.33 A practical earth electrode that provides a low ground resistance is not always easy to obtain.

Fig. 3-12. An electrical circuit with too high a resistance to ground.



Actually, the earth is a relatively poor conductor of electricity as compared to normal conductors like copper wire. But, if the area of a path for current is large enough, resistance can be quite low and the earth can be a good "conductor."

3.34 To understand why earth resistance or ground must be low, apply Ohm's Law to the following problem: Assume that you have a 4,000-volt supply, 2,300 volts to "ground," with a resistance of 13 ohms as illustrated in Fig. 3-12. Now, assume that an exposed wire in this system touches a motor frame that is connected to a grounding system having a 10-ohm resistance to ground. There will be a current of 100 amperes, from the motor frame, through the fault to a ground (marked "Danger" in Fig. 3-12).

3.35 If you should touch the motor frame and are grounded (perhaps by standing in a wet area), you could be subjected to 1,000 volts (10 ohms x 100 amperes). This would be more than enough to kill you instantly. If, however, the earth resistance was less than one ohm, the "shock" you'd get would be under 100 volts (1 x 100) and you would likely live to correct the fault.

3.36 Equipment can also be damaged similarly by over-voltages caused by high-resistance grounding. For your own protection, remember that only a small amount of electrical current – as little as 0.1 ampere for one second – can be fatal! An even smaller amount can cause you to lose muscular control, and perhaps disturb the rhythm of your heart. These currents can occur in your body at voltages of 100 volts, if your skin is moist.

Use of a Megohmmeter

3.37 In general, the higher the rated voltage of the equipment to be tested, the higher the megohm range required to measure normal as well as "safe" values of insulation resistance. Small low-voltage equipment may have very high normal insulation resistance, and, at the same time, its safe values may come well within the range of a 50- or 100-megohm instrument. The supply voltage is usually 250 or 500 volts D-C. On high voltage electrical equipment, instruments with resistance ranges up to 2,000, 5,000, and 10,000 megohms may be used; instrument generators rated up to 1,000 or 5,000 volts are common in such meters.

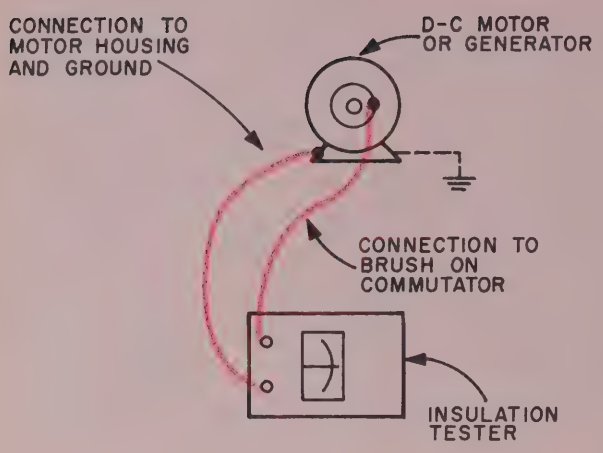
3.38 The voltage should never be higher than considered safe to apply to the apparatus under test. However, the voltage rating of a megohmmeter instrument does not have to be as high as that of the equipment under test in order to obtain completely reliable readings of insulation resistance.

3.39 Five hundred-volt megohmmeter instruments are most popular for general maintenance and troubleshooting. This voltage is high enough for testing many types of high-voltage equipment and yet is not considered too high to apply to ordinary low-voltage equipment.

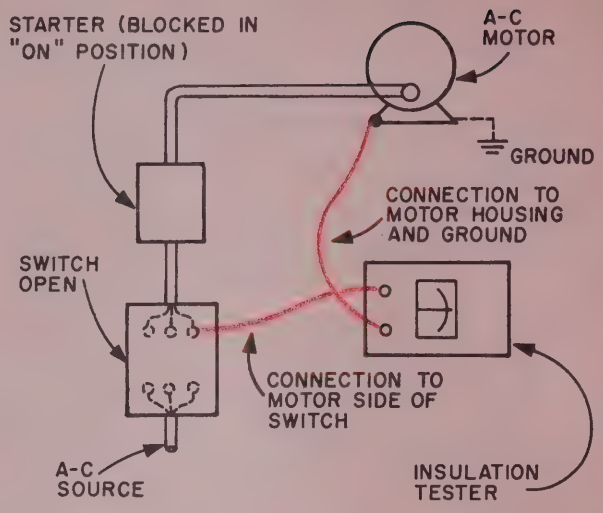
3.40 If very large rotating machines or very long cables are to be tested, constant-voltage instruments should be used.

3.41 By using constant-voltage instruments, such as the megohmmeter, you can be confident that no higher than rated testing voltage will be applied to the apparatus under test.

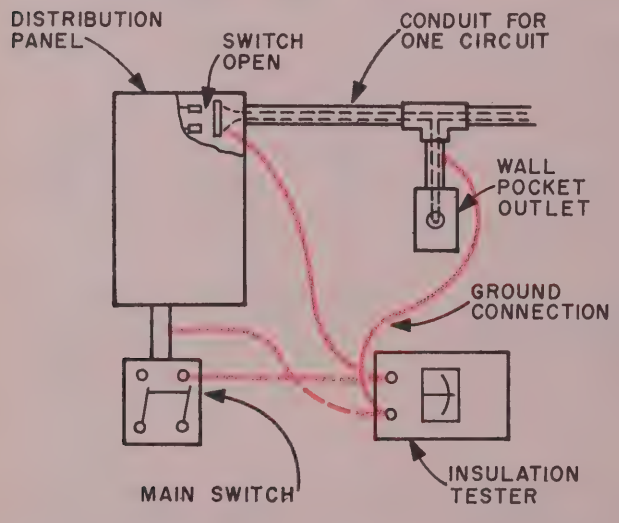
3.42 The megohmmeter is one of the more common instruments you will use in your total electrical maintenance job responsibilities. Applications of this type instrument will be encountered most in equipment maintenance and troubleshooting.



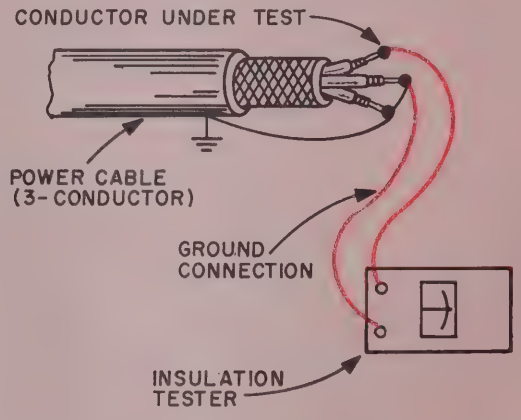
D-C motors and generators can be connected to the tester, as illustrated. This way you can test the brush rigging, the field coils, and the armature all at the same time. If an insulation weakness is indicated, you can lift the brushes off the commutator and test the brush rigging and field coils separately. Then, with the brushes still lifted, you can connect the tester to check the armature alone.



A-C motors and starting equipment can be tested, as illustrated, connecting one side of the tester to the motor side of the main switch; the second test connection is clipped to the motor housing. If an insulation weakness is indicated, the tester should be connected to check the motor and starter separately.



Wiring Installations can be checked from a panelboard as illustrated. The solid-line connections to the tester show how to test each circuit to ground, working from the distribution panel. Dashed-line connections at the main switch show how to test an entire wiring system to ground, provided all switches on the distribution panel are closed.



Low-Voltage Cables can be tested by first disconnecting both ends (to avoid error due to leakage across or through switchboards or panelboards), and then connecting the conductor under test to one terminal of the tester. All other conductors (two in this case) are connected together and grounded. Then they are in turn individually connected to the other terminal ground of the instrument in the same manner. Similarly, you can measure other insulation resistances such as between conductor and outside protective sheath, between conductors, and so on.

Use these programed exercises to help check your learning progress.

3-9. A megohmmeter is frequently called a _____.	3-9. MEGGER® REF: 3.16
3-10. The megohmmeter is designed to measure very _____ resistances.	3-10. HIGH resistances REF: 3.17
3-11. Most portable megohmmeters obtain their operating power from a _____-_____ _____.	3-11. HAND-DRIVEN GENERATOR REF: 3.18
3-12. A megohmmeter will NOT cause insulation _____.	3-12. BREAKDOWN or DETERIORATION REF: 3.24
3-13. Good insulation has high _____.	3-13. RESISTANCE REF: 3.30
3-14. Electrical equipment can be damaged by an over-voltage caused by high-resistance _____.	3-14. GROUNDING REF: 3.36
3-15. Most megohmmeter instruments for general maintenance use generated voltages of at least _____ volts.	3-15. 500 REF: 3.39
3-16. When testing the insulation of long cables, you should use instruments that have _____ _____.	3-16. CONSTANT VOLTAGE REF: 3.40

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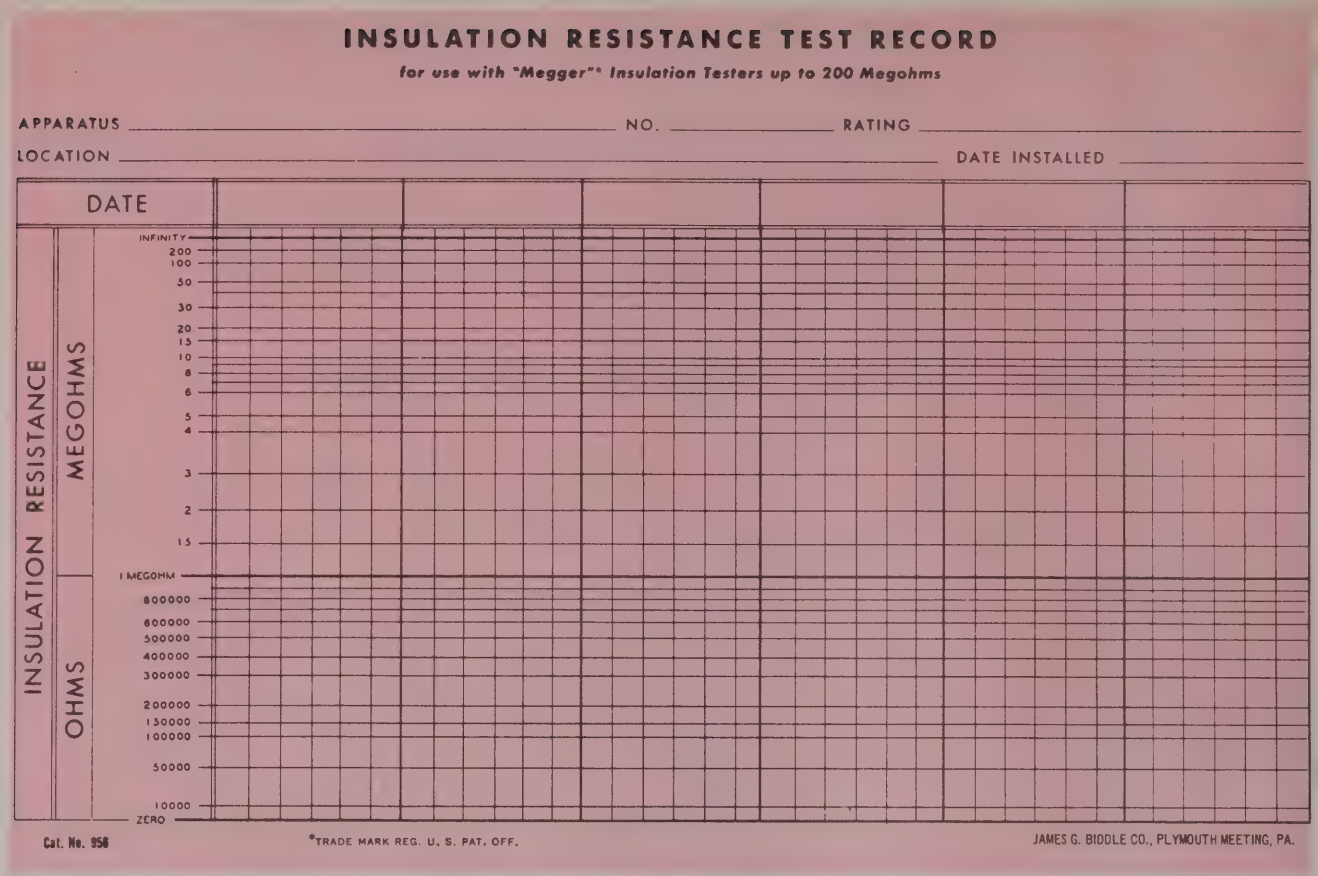


Table 3-1. A practical resistance test record sheet.

Instructions for Using an Insulation Tester

Checking the Instrument

Place instrument on a firm and fairly level base. The pointer may point anywhere over the scale until the instrument is operated.

Check for an INFINITY reading by turning crank at normal speed in clockwise direction. With nothing connected, the pointer should move promptly to Infinity.

Check for a ZERO reading by short-circuiting the test terminals. Turn the crank slowly. The pointer should move promptly to Zero. There is no Zero adjustment.

To Make a Test

Be sure the apparatus to be tested is NOT live.

Use well-insulated test leads having single-conductor wire.

Check the test leads. With the leads connected to the instrument terminals and with the opposite ends separated, turn the crank at normal speed. The pointer should indicate Infinity. Touch the test leads together and turn the crank. The pointer should indicate Zero. Do not use leads that are frayed, broken or damaged.

Make the test connections and operate according to the directions on the instrument.

CAUTION: Do NOT use the instrument if its terminal or operating voltage is in excess of the safe value for the equipment under test.

SELF-CHECK QUIZ

3-1. The source of energy for operating an ohmmeter is obtained from

a. the line being measured
b. any 120 volt source
c. a rectifier cell
d. a battery

3-2. An ohmmeter is calibrated by shorting the test leads together and adjusting the pointer to zero by means of

a. a small screwdriver
b. the COMMON jack
c. the variable resistor
d. a pointer spring

3-3. When, if ever, may an ohmmeter be used in an energized circuit?

a. When the potential is less than 125 volts
b. Only when an instrument transformer is used
c. Only when one side is grounded
d. Never

3-4. Multiplication features are incorporated in an ohmmeter to enable the meter to

a. measure very high resistance values
b. measure values with the least error
c. be multipurpose in its application
d. have less power consumption

3-5. If it takes 0.02 mA. to deflect the pointer of an ohmmeter to half scale when set in multiplier position Rx1, how much current is required to give the same deflection when set in position Rx100?

a. 0.2 mA.
b. 0.02 mA.
c. 0.002 mA.
d. 2.0 mA.

3-6. The megohmmeter is expressly designed to measure which of the following?

a. Very low resistances
b. Very high resistances
c. Faulted power lines
d. Overload protection devices

3-7 Before and after taking megohmmeter tests of large equipment, be sure to

a. discharge charged capacitors
b. adjust the pointer to midpoint
c. check output voltage of generator
d. ground the instrument

3-8. What type record can help you to be aware of a circuit's insulation condition?

a. Resistance test record
b. Power demand record
c. Record of maximum loads
d. Record of power factor resistance

3-9. A good industrial plant grounding system should provide protection against

a. overloads due to power surges
b. static electricity from friction
c. over-voltages
d. insulation breakdown

3-10. What is the highest common voltage rating for megohmmeter instrument generators?

a. 500 volts
b. 1000 volts
c. 2500 volts
d. 5000 volts

ANSWERS TO SELF-CHECK QUIZ

3-1. d. A battery. REF: 3.02.

3-2. c. The variable resistor. REF: 3.05.

3-3. d. Never. REF: 3.08.

3-4. b. Measure values with the least error. REF: 3.12.

3-5. b. 0.02 mA. REF: 3.12, 3.14.

3-6. b. Very high resistances. REF: 3.17.

3-7. a. Discharge charged capacitors. REF: 3.27.

3-8. a. Resistance test record. REF: 3.30, Table 3-1.

3-9. b. Static electricity from friction. REF: 3.31.

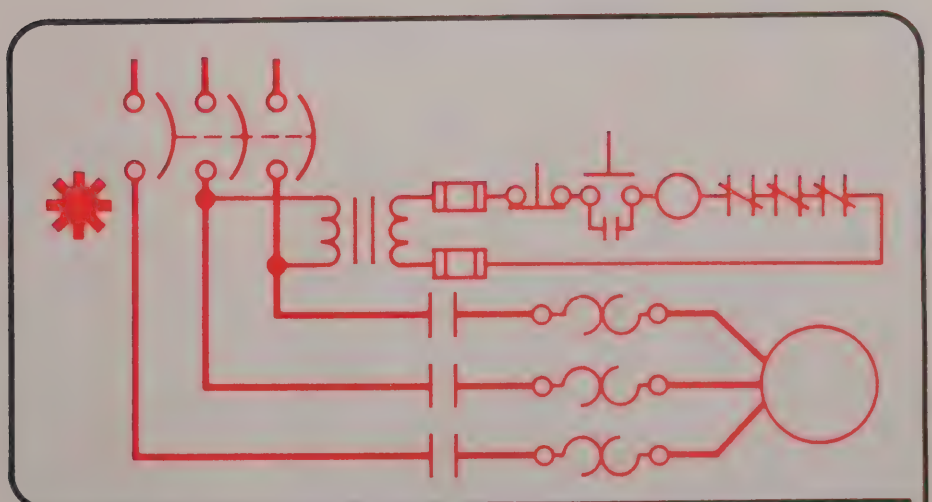
3-10. d. 5000 volts. REF: 3.37.

LESSON FOUR

A-C METERING PRINCIPLES

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Four — A-C Metering Principles

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Lesson Four — A-C Metering Principles

Preface

The basic electrical instruments used to measure direct current and voltage values have been explained in previous lessons of this unit. This lesson explains indicating instruments that measure alternating current, instruments such as rectifier A-C meters, electrodynamometers, and moving-iron meters. A good maintenance electrician must have a working knowledge of all of these instruments.

This lesson also explains the characteristics and practical applications of industrial measuring instruments that measure electricity in circuits, devices, and controls.

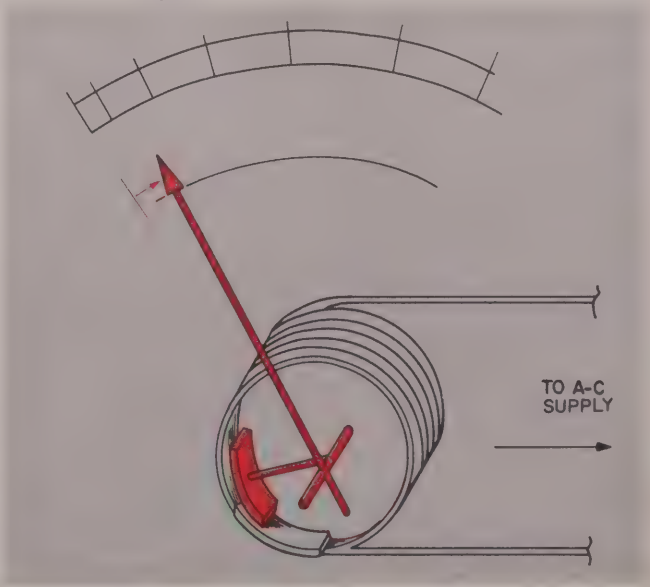
How A-C instruments operate, and the principles explained in this lesson, will help you understand the operating characteristics of other electrical instruments used in industrial plants today.

Moving-Iron Meter Principles

4.01 The D'Arsonval movement is used in some A-C panel instruments, but a small rectifier must be connected to the meter movement to rectify the A-C input before it is applied to the meter movement. The type of meter commonly used in measuring A-C values is the MOVING-IRON meter. Switchboard meters for measuring A-C voltage and current usually use this type meter movement. The moving-iron voltmeter or ammeter is usually self-contained when used in low-current or voltage circuits. Unlike the PM-MC instrument, which employs permanent magnets, the moving-iron meter depends on induced magnetism for its operation. The principle of repulsion between two concentric iron vanes, one fixed and one movable, is employed. The vanes are placed inside a coil with a pointer attached to the movable vane, as illustrated in Fig. 4-1.

4.02 To some extent, the configuration of the moving-iron instrument is just the opposite of the permanent-magnet, moving-coil instrument. The coil through which the measuring current flows is not movable, but fixed in position on the instrument frame; the "magnet" is the moving member, and it is attached to the shaft, which carries the indicating pointer illustrated in Fig. 4-2. The magnet is not a permanent magnet because, if it were, the instrument would measure only direct current – an alternating current in the field would cause the magnet to move first in one direction and then in the other with each reversal of the field,

Fig. 4-1. Operating principle of a moving-iron meter.



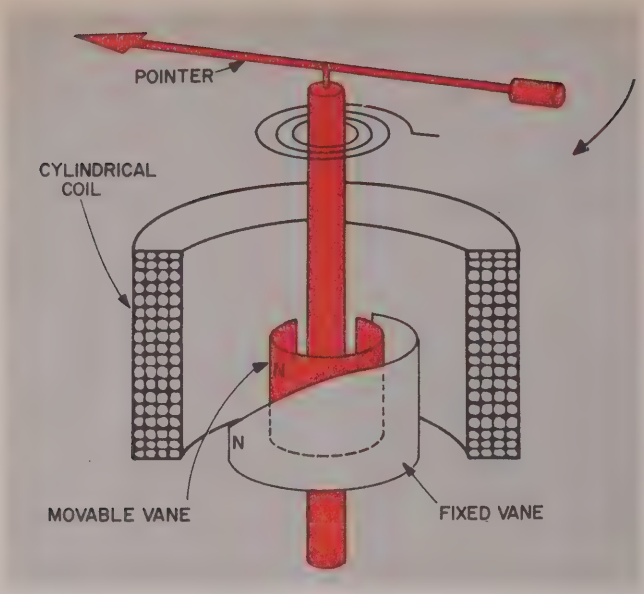


Fig. 4-2. Moving-iron meter movement construction.

with the result that the pointer would merely vibrate about the zero point on the scale.

4.03 When current flows through the coil, both iron vanes become magnetized, with north-polarity at one end and south-polarity at the other end, as shown in Fig. 4-2, depending on the direction of current through the coil. Because like poles repel, the movable element turns against the springs.

4.04 The vanes are made in different shapes, one rectangular and one tapered, by design. This difference results in relatively uniformly-spaced values on the scale.

4.05 When no current is flowing through the coil, the movable vane is positioned opposite the larger portion of the tapered fixed vane, and the scale reading is zero. The amount the vanes are magnetized depends on the strength of the field, which, in turn, depends on the amount of current flowing through the coil. Repulsion is greater opposite the large end of the fixed vane than it is near the small end. Therefore, the movable vane moves toward the smaller end to a point that is proportional to the strength of the coil current. The movement stops at the point where the force of repulsion is equal to the restoring force of the spring.

4.06 Since the repulsion is always in the same direction (toward the smaller end of the fixed vane) regardless of the direction of current flow through the coil, the moving-iron meter will operate on either D-C or A-C circuits.

Damping Methods

4.07 Magnetic damping is accomplished by supporting a thin aluminum or copper vane between the poles of a small permanent magnet, and positioning it so the deflection of the moving system causes the damping vane to cut the flux of the damping magnet, thus inducing current in the vane. The field produced by this current interacts with that of the damping magnet, which tends to oppose the motion of the moving system and bring it to rest quickly. Magnetic damping is also used in other instruments, as illustrated in later lessons.

4.08 Mechanical, or air damping, in this type of instrument is provided by an aluminum vane attached to the shaft in such a way that, as the shaft moves, the vane moves in an enclosed air space.

4.09 If a moving-iron meter has been designed for use as an ammeter, the coil is wound with relatively few turns of large wire to carry the rated current.

4.10 If this type of instrument is designed for use as a voltmeter, the coil is wound with many turns of small wire. Portable voltmeters are made with self-contained series resistors for ranges up to 750 volts. Higher ranges are obtained by the use of additional external multipliers.

Applications of Moving-Iron Meters

4.11 Because of their simplicity, their relatively low cost, and the fact that no current is conducted through the moving element, moving-iron meters are extensively used to measure current and voltage in A-C power circuits. When a moving-iron meter movement is used in A-C circuits, it has a full-scale accuracy of 0.5 percent.

4.12 However, because the reluctance-value of the magnetic circuit is high, the moving-iron meter requires much more power to produce full-scale deflection than that required by a PM-MC meter of the same range. Therefore, moving-iron meters are seldom used in high-resistance, low-power circuits.

Use these programed exercises to help check your learning progress.

4-1. The moving-iron meter depends on _____ _____ for its operation.	4-1. INDUCED MAGNETISM and the principle of magnetic repulsion. REF: 4.01
4-2. In the moving-iron meter, the iron vanes are located inside the _____ _____.	4-2. OPERATING COIL through which the measuring current flows REF: 4.01, Fig. 4-1
4-3. One moving-iron vane is rectangular and the other one is tapered to obtain more uniformly spaced _____ on the scale.	4-3. CALIBRATIONS or READINGS REF: 4.04
4-4. The amount the iron vanes are magnetized depends on the amount of _____ _____.	4-4. CURRENT FLOW through the coils REF: 4.05
4-5. A thin aluminum or copper vane supported between the poles of a small permanent magnet provides _____ _____.	4-5. MAGNETIC DAMPING REF: 4.07
4-6. Portable moving-iron voltmeters are made with self-contained multipliers (series resistors) for ranges up to _____ _____.	4-6. 750 VOLTS. Higher ranges are obtained with the use of external multipliers REF: 4.10
4-7. Moving-iron meters are used extensively for A-C voltage and current measurements because no current flows through the _____ _____.	4-7. MOVING ELEMENT REF: 4.11
4-8. The moving-iron instrument is seldom used in high-resistance, low-power circuits because of the high _____ in the magnetic circuit.	4-8. RELUCTANCE REF: 4.12

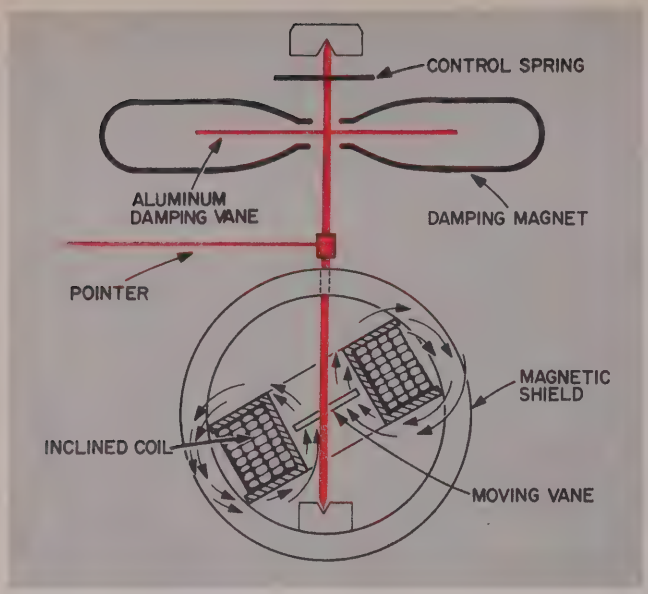


Fig. 4-3. Inclined-coil meter components.

Inclined-Coil Instruments

4.13 Another moving-iron meter movement widely used in high-grade A-C instruments is the inclined-coil movement illustrated in Fig. 4-3. This type of construction is used in both portable and switchboard instruments, thus providing a long, well-distributed scale.

4.14 The moving-iron principle is applied in the inclined-coil meter. It has a coil mounted at an angle to the shaft. Two soft-iron vanes are located inside the coil and attached at an angle to the shaft. When current flows through the coil, the vanes tend to line up with magnetic lines passing through the center of the coil at right angles to the plane of the coil. The vanes rotate against spring action to move the pointer across the scale.

4.15 The soft-iron vanes line up with the magnetic lines regardless of the direction of current flow through the coil. Therefore, the inclined-coil meter can be used to measure either alternating current or direct current. Aluminum vanes and damping magnets provide electromagnetic damping.

4.16 Like the moving-iron meter, the inclined-coil type requires a relatively large amount of current for full-scale deflection and is seldom used in high-resistance, low-power circuits.

4.17 The inclined-coil instrument is wound with few turns of relatively large wire when used as an ammeter, and with many turns of small wire when used as a voltmeter.

Electrodynamometer — Operating Principles

4.18 The ELECTRODYNAMOMETER mechanism, frequently called a DYNAMOMETER or ELECTRODYNAMIC mechanism, is adaptable to a greater variety of measurements than any of the instruments previously described. It is especially useful in A-C measurement. It provides a more efficient means of measuring low values of alternating current than is afforded by the moving-iron instrument. The electrodynamometer is often used for measuring A-C voltage.

4.19 An additional function, not served by the instruments previously explained, is the measurement of power (watts). In a D-C circuit, the power is the product of the current times the voltage (I x E); hence, it is not necessary that a separate instrument be used to determine the power consumed.

4.20 In an A-C circuit, however, the current and voltage are not always in phase; that is, they may not reach their maximum values at the same instant. Consequently, the power is affected by the phase displacement of current and voltage, and power measurement therefore requires an instrument that takes into consideration this phase difference (power factor). The electrodynamometer performs this task well; and it is extensively used for measurement of power, as well as for measurement of current and voltage.

4.21 The deflecting torque in an electrodynamometer results from the interaction of the magnetic fields set up by the meter coils illustrated in Fig. 4-4. One of these magnetic fields is produced by current in a moving coil armature, and the other by current in a stationary field coil. The magnetic field of the stationary coil corresponds to that of the permanent magnet in the conventional D-C mechanism. It differs primarily in that its strength is not constant, but varies with the amount of current in the field coil. This variation in field strength produces a corresponding variation in torque. Hence, the torque of the electrodynamometer is governed not only by the

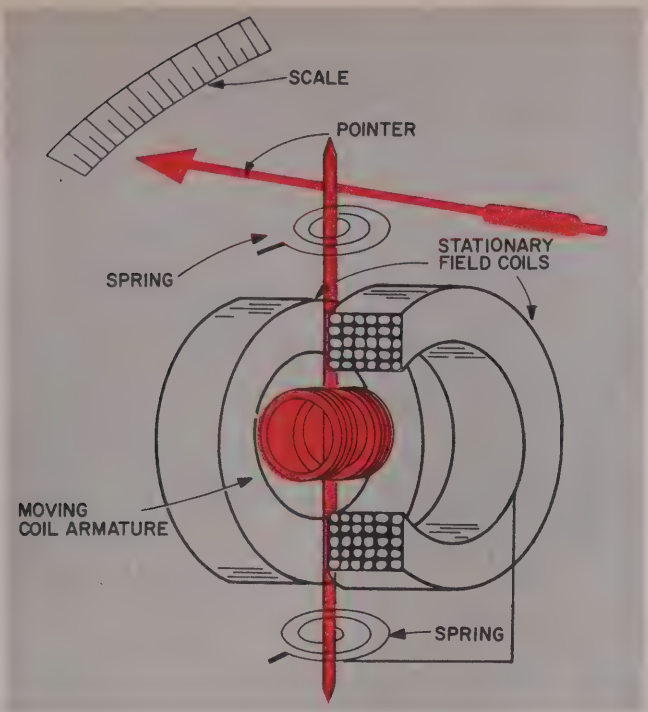


Fig. 4-4. Electrodynamometer components.

armature current (as in the permanent-magnet moving-coil instrument) but also by the field current. The torque is proportional to the instantaneous product of the field current and the armature current, and it is controlled by changes in either the field or the armature currents.

4.22 Electrodynamometers are the most fundamental of all indicating devices now used. This device is current sensitive – the pointer moves because of current flowing through turns of wire.

4.23 The electrodynamometer differs from the galvanometer (PM-MC movement) in that no permanent magnet is used. Instead, two stationary coils are utilized to produce the magnetic field, as illustrated in Fig. 4-4.

Principal Parts of an Electrodynamometer

4.24 The central shaft on which the movable coils are mounted is restrained by spiral springs that hold the pointer at zero when no current is flowing through the coil. The springs also serve as conductors for delivering current to the movable coils. Because these conducting springs are very small, the meter cannot carry large current values.

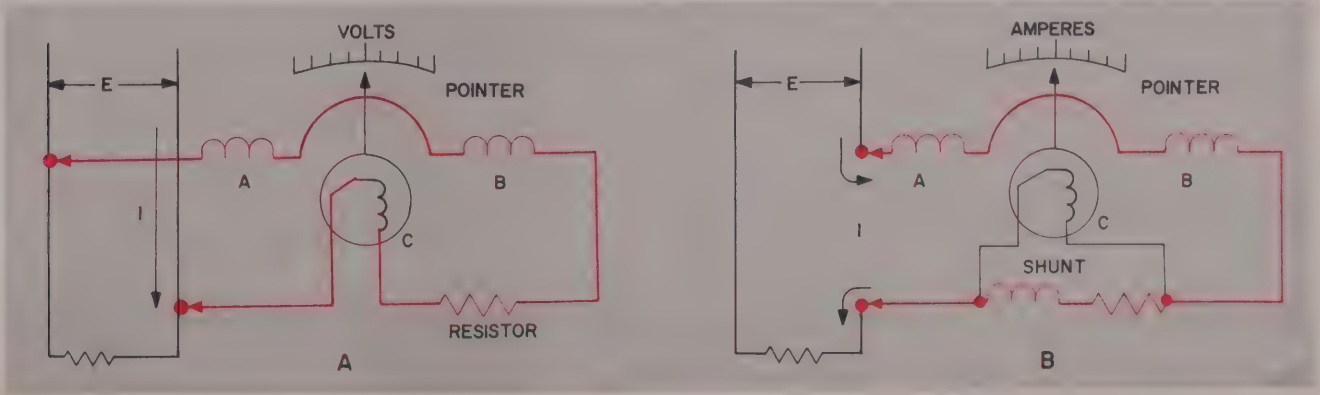
4.25 The two fixed coils are connected in series and positioned coaxially (on a common axis) with a space between them. The two movable coils are also positioned coaxially, and are connected in series. The two pairs of coils (fixed and movable) are further connected in series with each other in the movable-coil unit, which is mounted in pivots between the fixed coil, see Fig. 4-4.

Electrodynamometer Applications

4.26 Electrodynamometers depend upon the reaction between the current in one or more of the moving coils and the current in one or more of the fixed coils for their operation. As a result of the different circuit relationships obtainable through the use of this principle, electrodynamometers find widespread use in all alternating-current measurement. They are used extensively for measuring power as well as reactive volt-amperes in both single-phase and polyphase circuits. Frequently they are used for high-accuracy voltage measurement; and they provide a convenient means of measuring power factor and frequency, as well as for indicating synchronism in A-C circuits.

4.27 When used as a voltmeter, no change in construction is necessary because the current required is not more than 0.1 ampere. This amount

Fig. 4-5. Electrodynamic instrument circuits.



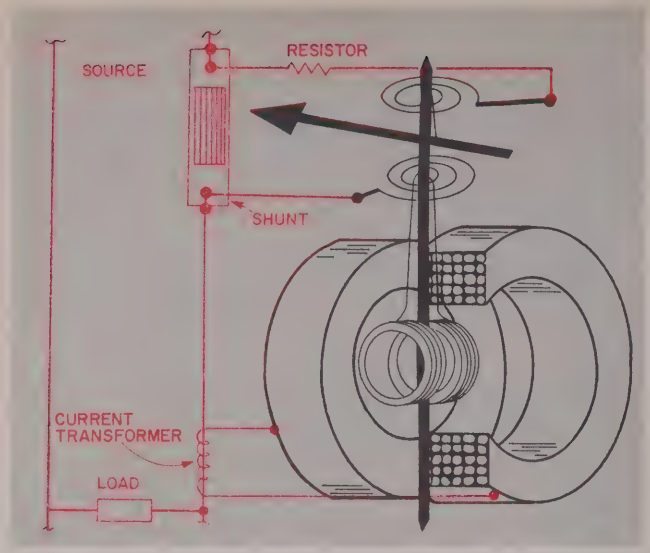


Fig. 4-6. Electrodynamometer connections to measure single-phase A-C current.

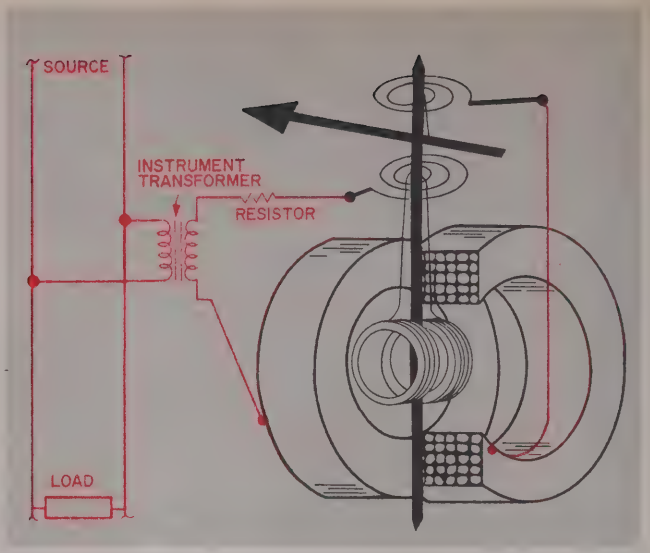


Fig. 4-7. Electrodynamometer connections to measure single-phase A-C voltage.

of current can be brought in and out of the moving coil through the springs without damage. The internal circuit connections of an electrodynamometer used as a voltmeter are illustrated in Fig. 4-5(A). The fixed coils A and B are wound with fine wire (because the current through them will be no more than 0.1 ampere). They are connected directly in series with the movable coil C and the series current-limiter resistor.

4.28 When used as an ammeter, a different construction must be used, because the large currents that flow through the meter cannot be carried through the moving coils. The stationary coils A and B illustrated in Fig. 4-5(B) are generally wound with heavier wire, wire able to carry up to five amperes. An inductive shunt is in parallel with the moving coils. The shunt permits only a small part of the total current to flow through the moving coil. This small part of the current is directly proportional to the total current carried through the instrument. The shunt has the same ratio of reactance to resistance as the moving coil, thus the instrument will be reasonably correct at all frequencies with which it is designed to be used.

4.29 The meter is mechanically damped by means of aluminum vanes that move in enclosed air chambers. Electrodynamometers are very accurate, but they do not have the sensitivity of the D'Arsonval meter.

4.30 Compared to the moving-iron meter, the electrodynamometer is more efficient and better adapted to applications requiring high accuracy.

Electrodynamometer Circuit Connections

4.31 When the electrodynamometer is used to measure alternating current, its coils are connected in series so that the same current flows in both coils. External connections are made as illustrated in Fig. 4-6. The meter's scale is somewhat crowded at the lower end, it opens up near the center, and is again crowded at the upper end. The crowding at the upper end of the scale occurs because the rate of increase in deflecting torque becomes less as the armature coils approach the position where they become parallel to the field coils.

4.32 Because an electrodynamometer's coils are connected in series, it is readily adapted to voltage measurement with a suitable series resistor (Fig. 4-7). When measuring either A-C voltage or current, the electrodynamometer indicates rms values.

4.33 The measurement of power by means of the electrodynamometer is possible because the torque varies with changes in either field or armature current and that torque is proportional to their product. A simple wattmeter-connection is illustrated in Fig. 4-8. The field coil of the mechanism is connected in series with the line, and the armature is connected, through a resistor,

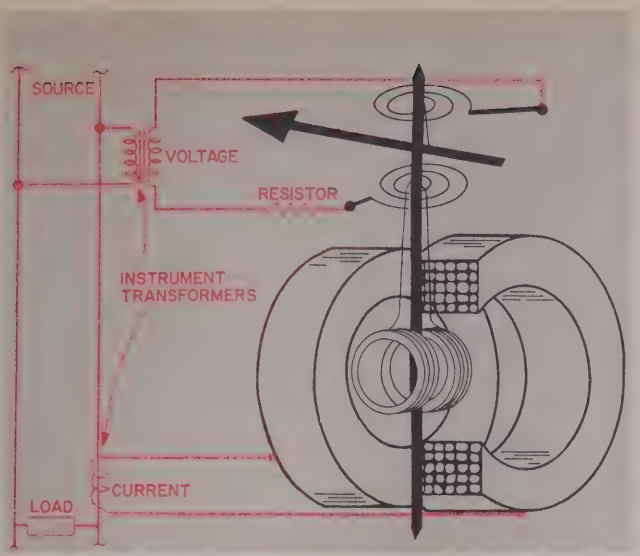


Fig. 4-8. Electrodynamometer connections to measure A-C power.

across the line. The field flux is proportional to the line current, the armature flux is proportional to the line voltage, and the instantaneous torque of the instrument is proportional to the instantaneous product of line current and voltage. This product represents the instantaneous value of power in the circuit, and the meter indicates the average of the power pulses, which therefore can be calibrated in watts.

4.34 Note that the electrodynamometer indicates the real power of an A-C circuit in which the power is not equal to the product of volts and amperes, but is equal to the product of the voltage and the part of the current that is in phase with the voltage. This power indication is important in A-C measurement because the current does not always reach its maximum value at the same instant that the voltage reaches its maximum, but generally lags behind or leads the voltage, depending upon whether the circuit load is more inductive or more capacitive.

4.35 When connecting an electrodynamometer, the instantaneous polarity of the flux of each coil must be considered, as this governs the direction the moving element moves. But when the instrument is used for only voltage or current measurement, the coils are connected internally, and you need not consider polarity when connecting the instrument in the circuit.

4.36 Where the electrodynamometer instrument is used for power measurement, the instantaneous direction of current through each coil is determined by the polarity of the circuit connection, and you must connect the instrument properly to get deflection in the proper direction. This is most important in polyphase instrument power measurements. To indicate the proper method of connection, identify each terminal of the coils with their polarities, plus or minus, and those terminals should be connected to the like-polarity side of the line to obtain proper meter deflection.

4-9. The inclined-coil meter requires a relatively _____ amount of current for full-scale deflection.	4-9. LARGE. It is seldom used in low power circuits REF: 4.16
4-10. The electrodynamometer mechanism is frequently called a _____ or _____ mechanism.	4-10. DYNAMOMETER or ELECTRO-DYNAMIC REF: 4.18
4-11. In an A-C circuit, power is affected by the phase displacement of _____ and _____.	4-11. CURRENT and VOLTAGE REF: 4.20
4-12. The deflecting torque developed in an electrodynamometer is a result of the interaction of two _____ _____.	4-12. MAGNETIC FIELDS set up by the meter coils REF: 4.21
4-13. An electrodynamometer differs from the PM-MC type because no _____ _____ is used in the electro-dynamometer.	4-13. PERMANENT MAGNET REF: 4.23
4-14. When compared with the moving-iron meter, the electrodynamometer is more _____ and _____.	4-14. EFFICIENT and ACCURATE REF: 4.30
4-15. An electrodynamometer is adaptable for measuring power because its torque varies with any changes in the _____ or _____ current.	4-15. FIELD or ARMATURE and the torque is proportional to the product of the two REF: 4.33
4-16. When connecting an electrodynamometer for power measurement, you must be sure to have correct _____ _____.	4-16. POLARITY CONNECTIONS REF: 4.36

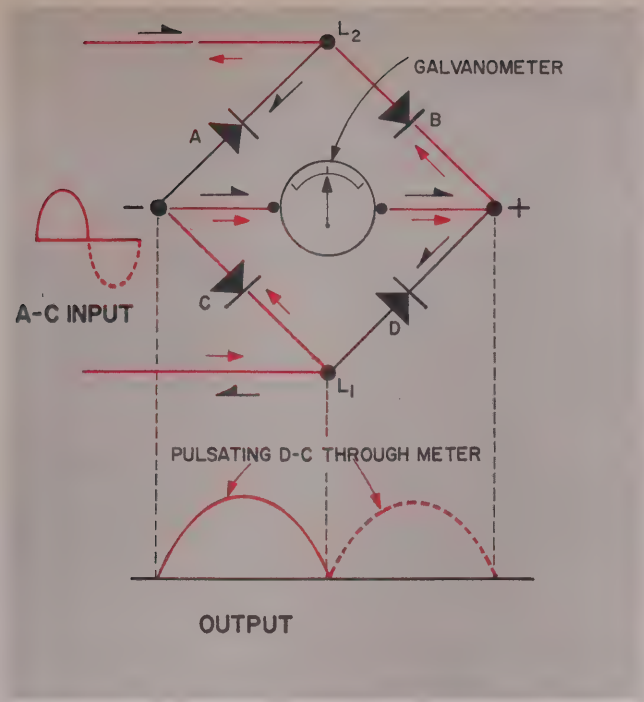


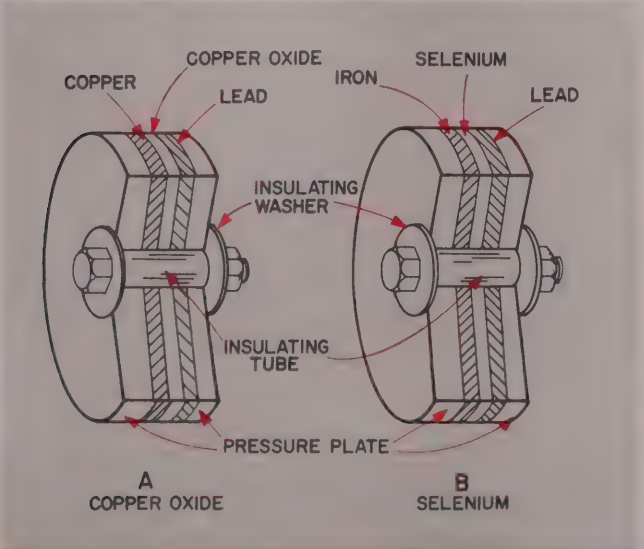
Fig. 4-9. Full-wave rectifier A-C meter connections.

A-C Meter Rectifiers

4.37 Many A-C instruments use a rectifier and D'Arsonval movement to measure A-C quantities. The rectifier is small and it is usually placed inside the meter case.

4.38 The rectifier is usually of the dry-plate type (made of copper-oxide or selenium), and it is arranged in a full-wave bridge circuit, as illustrated in Fig. 4-9. The full-wave bridge converts the incoming A-C to D-C to operate the D'Arsonval movement. If the voltage being measured has a sine waveform, as illustrated in Fig. 4-9, the path of current flow on the first half-cycle is from terminal L_1 through rectifier C, through the instrument, and then through rectifier B, thus completing its path back to terminal L_2. The next half-cycle of the input voltage (indicated by the dotted sine wave) causes the current to pass through rectifier A, through the instrument, and through rectifier D, thus completing its path back to the source.

Fig. 4-10. Construction of metallic rectifiers.



4.39 In spite of the errors introduced by varying waveforms and frequency, these A-C voltmeters provide accurate measurements up to 10 kilohertz. When used as A-C ammeters, they are accurate up to 15 milliamperes. They are not suitable for measuring larger currents because the temperature coefficient of the rectifier makes it inadvisable to use larger shunts, and higher currents create excessive heat.

4.40 Aging in a rectifier causes changes in the calibration of the instrument. Because of this aging, such instruments must be recalibrated from time to time.

4.41 A rectifier instrument reads the AVERAGE value of the A-C quantity. However, because the EFFECTIVE, or rms values, are more useful, rectifier A-C meters are calibrated to read rms values, or 1.11 times the average value.

Instrument Rectifier Construction

4.42 A rectifier is a device that offers a high resistance to current flow in one direction but not in the other, and is, effectively, a unidirectional (one way) conductor, mostly used for converting alternating current into direct current.

4.43 A metallic rectifier consists of a conductor (copper, with a copper-oxide layer formed on one side) and a soft metal, such as lead, pressed onto the copper-oxide layer, as illustrated in Fig. 4-10(A). The selenium rectifier is made up in much the same way as illustrated in Fig. 4-10(B).

4.44 An electron current can readily pass from the copper to the copper-oxide disk, but a very high resistance is offered to electron flow in the opposite direction.

4.45 Rectifier cells are usually made as circular or square disks with a mounting hole in the center.

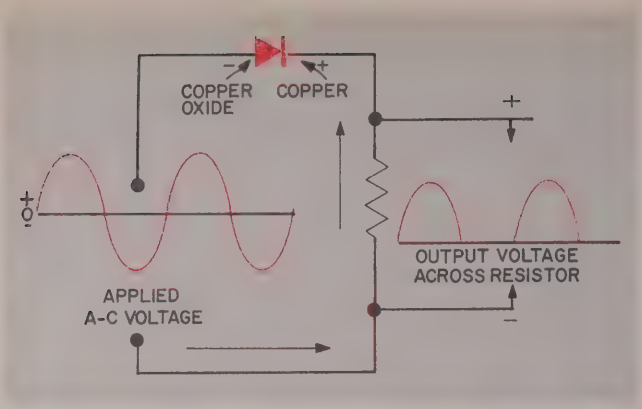


Fig. 4-11. Waveforms in an A-C circuit, which uses a copper-oxide rectifier.

4.46 A rectifier stack is a number of rectifier cells assembled together, as illustrated in Fig. 4-10(A)(B), for use on higher voltages. Each cell can stand about 11 volts A-C.

4.47 Where large current is encountered, the rectifier stacks are provided with cooling fins to dissipate the heat.

4.48 Cells and stacks can be connected in series to obtain required voltage ratings, or they can be connected in parallel for correct current rating and circuit connections for specific application.

4.49 The COPPER-OXIDE rectifier illustrated in Fig. 4-10(A) has the oxide formed on the copper disk before the rectifier unit is assembled. The electrons flow more readily from the copper to the oxide than from the oxide to the copper. External electrical connections are made by connecting the terminals between the left pressure plate and the copper, and between the right pressure plate and the lead washer.

4.50 For the rectifier to function properly, the oxide coating must be very thin. Each individual unit can stand only a low inverse (in the opposite direction) voltage. When designed for moderate or high-power applications, a rectifier consists of many individual units mounted in series on a single support. The lead washer enables uniform pressure to be applied to the units so the internal resistance can be reduced. (When units are connected in series, they normally present a relatively high resistance to current flow.) The heat developed by this internal resistance has to be removed if the rectifier is to operate satisfactorily: Thus, the need for cooling fins. The useful life of a rectifier is extended by keeping the temperature below 140°F. The efficiency of this type of rectifier is generally between 60 and 70 percent. The remaining 30 or 40 percent of the electrical power is dissipated as heat.

4.51 SELENIUM rectifiers function in much the same manner as copper-oxide rectifiers. A selenium rectifier, as illustrated in Fig. 4-10(B), is made up of an iron disk that is coated with a thin layer of selenium (a semi-conductor chemical element). The electrons flow more easily from the selenium to the iron than from the iron to the selenium.

4.52 A selenium rectifier may be operated at a somewhat higher temperature than a copper-oxide rectifier similarly rated. The efficiency is between 65 and 85 percent, depending on the circuit and the load. Like the copper-oxide rectifier, any practical number of units may be bolted together in series to increase the voltage rating. Larger element disks and the necessary cooling fins can be used for higher current ratings. Forced-air can also be used to cool large rectifiers.

4.53 The symbol for metallic rectifiers or diodes is shown in the circuit diagram in Fig. 4-11. The arrowhead of the symbol points opposite to the direction of electron current flow. The arrowhead is called the anode, the straight line of the symbol, which the arrowhead is pointing into, is called the cathode. The electron current flow is, therefore, from the cathode to the anode.

4.54 Figure 4-11 illustrates the voltage waveform obtained at the output of the A-C rectifier circuit. The output is called pulsating D-C. The metallic rectifier (or diode) allows electrons to flow only in one direction. The output waveform shows the positive half of an A-C cycle; because of its unidirectional characteristics, the diode does not allow the negative half of the A-C cycle to pass through.

4.55 Although Fig. 4-11 uses a copper-oxide rectifier, a selenium rectifier, silicon diode, or germanium diode can be used. The silicon diode is more commonly used today. The operation of the instrument is not altered in any way.

4.56 You will find the operating characteristics for rectifiers that were explained in this lesson will also be valuable to you in other areas of electrical maintenance work.

Use these programed exercises to help check your learning progress.

4-17. Many A-C meters use a rectifier and a D'Arsonval movement to measure A-C. The rectifier is usually placed inside the meter and is connected as a full-wave _____ _____.	4-17. BRIDGE CIRCUIT REF: 4.38
4-18. Aging of a copper-oxide or selenium rectifier causes changes in the _____ of a rectifier type instrument.	4-18. CALIBRATION, therefore these instruments must be recalibrated from time to time REF: 4.40
4-19. A rectifier is effectively a _____ conductor used primarily for converting A-C into D-C.	4-19. UNIDIRECTIONAL (one way) REF: 4.42
4-20. Rectifier cells and stacks can be connected in _____ to obtain the necessary voltage range requirements.	4-20. SERIES REF: 4.48
4-21. Rectifier cells and stacks should be connected in _____ to obtain different current ratings.	4-21. PARALLEL REF: 4.48
4-22. The efficiency of a copper-oxide rectifier is generally between 60 and 70 percent. The remaining 30 to 40 percent is dissipated as _____.	4-22. HEAT REF: 4.50
4-23. A selenium rectifier can be operated at higher _____ and _____ than a copper-oxide type of the same rating.	4-23. TEMPERATURE and EFFICIENCY REF: 4.52
4-24. Because of its _____ characteristics, a diode will allow electron flow in one direction.	4-24. UNIDIRECTIONAL REF: 4.54

MOVING-IRON VANE INSTRUMENT – An instrument that depends on the reactions, from the current, in one or more fixed coils acting upon one or more pieces of magnetic material, called vanes, in the moving system. One vane is fixed and the other is free to revolve, through a fixed angle, together with the instrument shaft. The rotation of the moving system is opposed by springs that return the pointer to zero when no current is flowing through the instrument. The direction of motion is the same, regardless of the direction of current through the instrument coil.

The inertia of the movable element prevents it from following the individual A-C alternations. The pointer deflection is approximately proportional to the square of the effective value of the current. These instruments are usually designed so the distances between the graduations on the upper three-quarters of the scale are uniform and those on the lower part of the scale are compressed.

ELECTRODYNAMOMETER – A meter that depends upon the reaction between the current in one or more moving coils and the current in one or more fixed coils for its operation; also called a dynamometer.

This meter consists of two coil groups, one stationary and one free to rotate within the other in such a manner that the axes of the coils take positions at right angles to each other. The rotation of the moving coil is caused by parallel conductors that carry currents so polarized that the coil groups repel each other to deflect the pointer. The rotation of the moving system is opposed by springs that return the pointer to zero when no current is flowing through the instrument. The direction of pointer motion still remains the same when the direction of the current is reversed in both coils.

The two coils are connected to provide a single circuit when used in voltmeters or ammeters. They can be connected to separate circuits for use as wattmeters. The coils are wound with fine wire for voltmeters and low-current ammeters, with heavy wire for high current ammeters. The moving-coil and connections limit the size of the windings, and, therefore, the range of ammeters.

Like moving-iron meters, electrodynamometers are usually designed so the upper part of the scale is uniform and the lower part of the scale is compressed.

An electrodynamometer mechanism is commonly used in a wattmeter. In this construction the moving coil is in series with a resistance, and the system is connected across the circuit as a voltmeter; and the other coil is connected in series with the load, as is an ammeter coil. Measuring D-C, the torque between these coils is proportional to the product of volts and amperes, or watts. Measuring A-C, the instrument recognizes the phase difference between volts and amperes, which is the power factor. Its readings then are proportional to the product of volts, amperes, and power factor.

RECTIFIER INSTRUMENT – The combination of a rectifier and a direct-current instrument that permits A-C measurements.

A rectifier instrument can consist of a sensitive D-C instrument mechanism connected in series with a copper-oxide or selenium rectifier. When a single rectifier unit is used in series with the instrument mechanism and the circuit, current flows only during one-half of an A-C cycle. This rectification results in a pulsating direct-current through the instrument, and a D-C meter element indicates the average value of this current. Usually, a D-C instrument is connected to a bridge-type rectifier, which rectifies both halves of the A-C cycle, thus producing a pulsating direct-current dependent on both halves of the A-C cycle. A D-C instrument will indicate the *average* value of this pulsating current.

Instruments that use rectifiers deflect according to the average value of the current through the instrument, but the scale is calibrated to indicate the *effective* value of the current.

Because of the relatively high efficiency and sensitivity of direct current PM-MC movements, they are used with copper-oxide rectifiers for the measurement and control of alternating current. Accurate A-C measurements at low ranges can be made very effectively.

SELF-CHECK QUIZ

4-1. The operation of the moving-iron vane meter depends on

a. a rectifier
b. retentivity
c. induced current
d. magnetic induction

4-2. A moving-iron meter will operate on

a. A-C circuits only
b. D-C circuits only
c. either A-C or D-C circuits
d. A-C or D-C when a rectifier is used

4-3. A thin aluminum or copper vane attached to the moving element is positioned between the poles of a small magnet in A-C instruments to provide

a. magnetic damping
b. magnetic repulsion
c. stable operating current
d. uniform scale reading

4-4. More power is required to operate a moving-iron meter than a PM-MC meter because of the magnetic circuit's high

a. resistance
b. reluctance
c. retentivity
d. resilience

4-5. Which of the following meter mechanisms is adaptable to a greater variety of measurements?

a. Inclined coil
b. Moving-iron vane
c. Electrodynamometer
d. Permanent magnet—moving coil

4-6. Electrodynamometers are used extensively for the measurement of

a. magnetic lines of force
b. resistivity
c. capacitor networks
d. power

4-7. When an electrodynamometer is used to measure power, it is graduated to indicate the

a. maximum power pulses
b. minimum power pulses
c. instantaneous power pulse
d. average of the power pulses

4-8. A rectifier is used in an instrument for the purpose of

a. measuring high voltage values
b. measuring high current values
c. converting A-C into D-C
d. making the instrument more stable

4-9. The useful life of a rectifier can be extended if the temperature is kept below 140° F. For this reason rectifiers

a. are stacked
b. have fins
c. are bridge connected
d. are series connected

4-10. The output voltage of a rectifier or diode is called

a. pulsating D-C
b. sine wave output
c. half-wave reactance
d. unidirectional current

ANSWERS TO SELF-CHECK QUIZ

4-1. d. Magnetic induction. REF: 4.01.

4-2. c. Either A-C or D-C circuits. REF: 4.06.

4-3. a. Magnetic damping. REF: 4.07.

4-4. b. Reluctance. REF: 4.12.

4-5. c. Electrodynamometer. REF: 4.18.

4-6. d. Power. REF: 4.26.

4-7. d. Average of the power pulses. REF: 4.33.

4-8. c. Converting A-C into D-C. REF: 4.42.

4-9. b. Have fins. REF: 4.47.

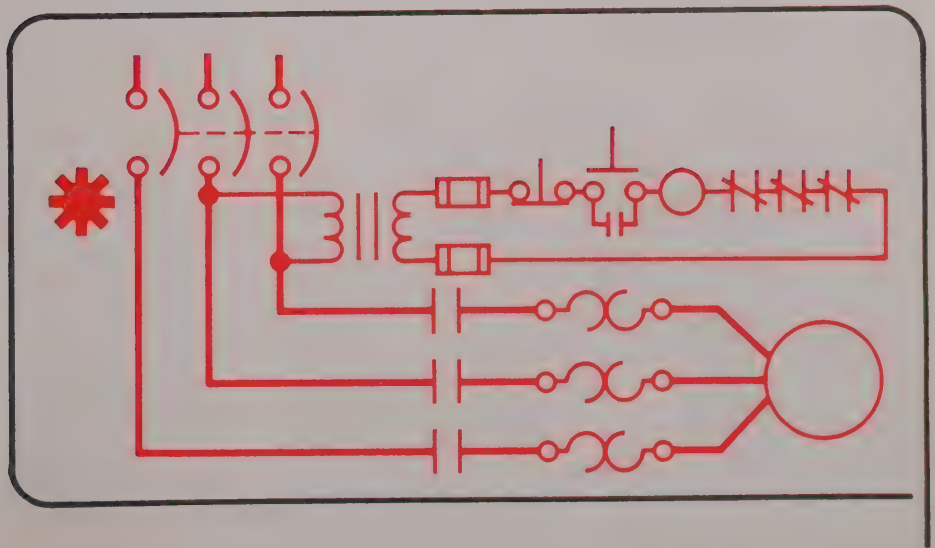
4-10. a. Pulsating D-C. REF: 4.54.

LESSON FIVE

A-C MEASUREMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Five — A-C Measurements

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Lesson Five — A-C Measurements

Preface

All electrical equipment is designed to operate at or within a range of specified voltage and current. Usually the equipment will work satisfactorily if the line voltage variations are not greater than plus or minus ten percent from the nameplate rating.

Actual operating behavior of electrical equipment can best be analyzed through the proper use of measuring instruments. A comparison of the voltage and current readings measured at the terminals can be made against the nameplate information on the equipment to determine whether or not the equipment is operating within its electrical specifications.

How this can be accomplished with the use of ammeters and voltmeters is explained in this lesson.

Meter Selection

5.01 The most important thing to consider when selecting a meter to take electrical measurements is the kind of current it will be used with — alternating or direct. For D-C, the permanent-magnet, moving coil meter gives good accuracy for voltage and current measurements. If less accuracy is required, one of the moving-iron meters can be used. Most D-C wattage checks can be done with the D-C ammeter and voltmeter, because voltage times current is equal to the power being used in a D-C circuit (W=EI).

5.02 For measurement of A-C voltage and current, the electrodynamometer movement is the most accurate device. Routine testing and trouble-shooting applications, however, can be performed satisfactorily by a moving-iron meter.

Fig. 5-1. Clamp-on voltammeter.

Amprobe Instrument Co.

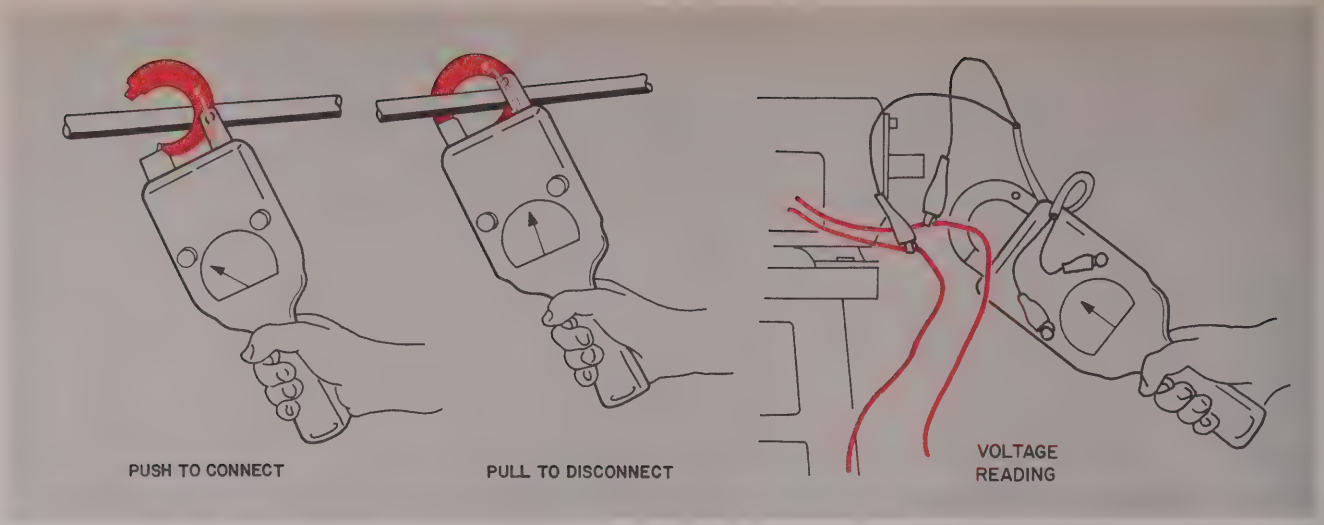


Fig. 5-2. Using a hook-on ammeter to measure current.

Split-Core A-C Instruments

5.03 Probably the most useful and commonly used instrument for everyday electrical maintenance is the SPLIT-CORE voltammeter, or split-core meter. The split-core meter is a unique member of the ammeter family because it measures the current flowing in a conductor, and indicates the value of the current on a graduated scale, by induction. It is commonly called a CLAMP-ON, a HOOK-ON, or SNAP-AROUND meter. A commonly used type is illustrated in Fig. 5-1. It eliminates the need to break the circuit under test, and does not require physical contact between meter and circuit. This type of instrument is ideally suited to applications where it is either impossible or impracticable to open the circuit. The split-core meter is safe, convenient, and a timesaver when obtaining alternating-current measurements.

NOTE – There are TWO distinct types of split-core meters – A-C and D-C. Although the principle for both is similar (induction), the differences between A-C and D-C current requires that the electrical circuitry employed to measure A-C be different than that used to measure D-C.

5.04 Since there is a fixed relationship between each of the variables; voltage, current, and resistance, the same meter movement can be used to measure them accurately. This is true of multimeters, which have multiple-measurement capabilities.

5.05 Split-core meters have been developed because of the great number of instances when it has not been convenient or desirable to open a circuit to insert an ammeter.

Construction of the Split-Core Meter

5.06 The split-core meter consists essentially of a current-transformer (with a split-core), and a rectifier-type instrument movement connected to the secondary. The current to be measured flows through the primary of the current transformer. The primary's split core permits the instrument to be "hooked-on" or snapped around the conductor without disconnecting it. The instrument is also usually constructed so that voltages can be measured. When measuring voltage, the meter switch must be set to VOLTS, and the leads connected from the voltage terminals on the meter to the terminals across which the voltage appears.

5.07 The method of using a hook-on instrument to measure current is illustrated in Fig. 5-2. To help you understand the operating principles of the instrument, the circuit diagram in Fig. 5-3 show the primary of the current transformer, the resistors and tapped secondary of the current transformer, and the moving coil, which is tapped to provide different voltage and current ratios.

5.08 The permanent-magnet, moving-coil instrument and the rectifier used to indicate voltage or current are similar to those described in previous lessons, only now the split-core transformer is

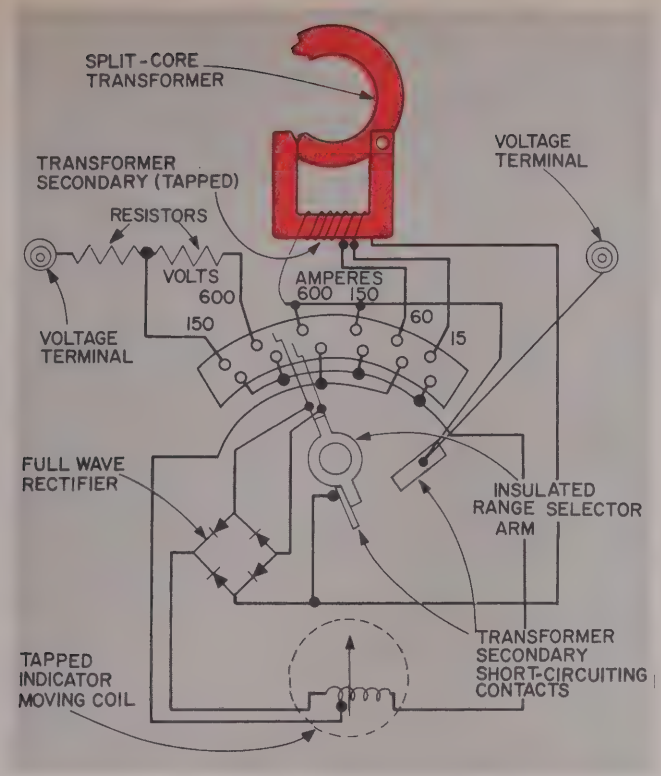


Fig. 5-3. Internal components of a hook-on volt-ammeter.

added to the ammeter circuitry to measure alternating-current.

5.09 The split-core transformer principle has an important bearing on the operation and the convenience-in-use of the hook-on or snap-around instrument. In some hook-on instruments, the split core of the transformer is provided with a toggle-action hinge. The core of the transformer can be opened without the use of a trigger or latch mechanism. When the core is in the open position, it snaps shut as the instrument is pushed against the conductor. A gentle pull will spring the core open and release the conductor, as illustrated in Fig. 5-2. The core is so designed that there is only one break in the magnetic path. The hinge has a close-fit, and the core is closed to a close-fit when the split-core opening is shut. It ensures minimum variation in the reluctance of the magnetic circuit.

5.10 To obtain a current measurement with a clamp-on meter, open the jaws of the instrument and place them around the conductor in which current is to be measured. Once around the conductor, allow the jaws to close securely. Now the pointer deflects on the meter scale, and indicates the value of current-flow in the conductor.

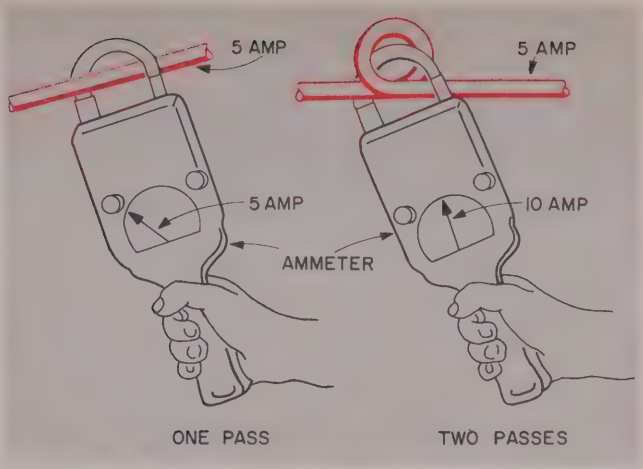


Fig. 5-4. Changing the transformer ratio of a split-core instrument.

5.11 When the core is clamped around a current carrying conductor, the alternating flux set up in the core induces a voltage in the meter's transformer secondary (see Fig. 5-3). This voltage is rectified and applied to the PM-MC Movement. The A-C range can be changed by changing taps on the transformer secondary with the use of a switching mechanism called a "range" switch.

5.12 Looping conductors more than once through the core is another means of range changing. Current below the maximum calibrated range of the instrument can be measured by looping the line conductor through the transformer opening so that two or more conductors pass through the opening, as illustrated in Fig. 5-4. This so decreases the transformer ratio that the indication of the instrument is increased to a value that is equal to the number of times the conductor passes through the opening, times the indication. To increase the use of the hook-on instrument, built-in resistors, which can be connected in the circuit by means of the range switch are provided, thus making the instrument available as a rectifier-type A-C voltmeter. The switch circuit is sometimes arranged so the instrument can remain connected for current or voltage measurement, and the range and quantity being measured can be selected by operating the range switch. Figure 5-5 illustrates the method by which motor current can be measured with a clamp-on instrument.

Voltage Measurement

5.13 A clamp-on meter can be designed to measure voltage as well as current. Such an

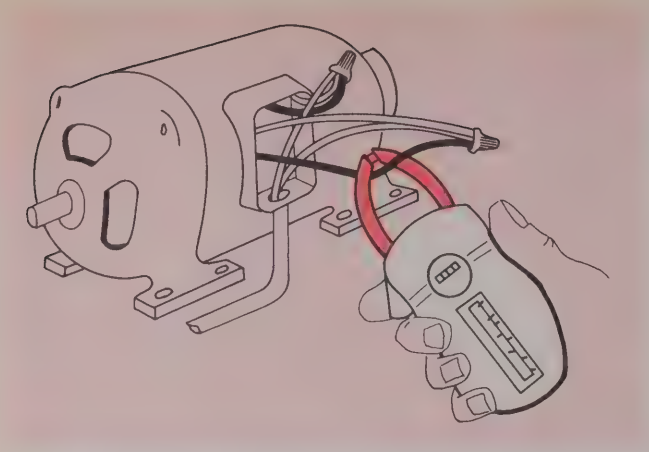


Fig. 5-5. Measuring motor current with a clamp-on ammeter.

instrument is equipped with one or more voltage scales (in addition to the current scales), and a pair of test leads to connect the meter to the points where voltage is present. When measuring voltage with a clamp-on meter, do not put the jaws around the conductor. (This could lead to an erroneous voltage reading.) Instead, the test leads are inserted into jacks or onto terminals provided on the meter, which presents the voltage to the meter without routing it through the secondary winding.

5.14 When a voltage is applied to the clamp-on meter, it is connected to the meter movement in series with a calibrating range resistor. When two or more voltage ranges are provided on the meter, a different value of series resistance is used for each range.

5.15 For any particular range, the value of the series resistance is such that with the maximum voltage of that range applied to the meter, the resulting current is just enough to deflect the meter pointer full-scale. Any lower voltage causes a correspondingly smaller deflection.

CAUTION: If a reading of zero volts is obtained when taking a voltage measurement, check the meter against a known voltage without changing the range to be certain the voltmeter is operating properly before you attempt to work on the circuit.

Current Measurement

5.16 A-C voltage measurement is accomplished by shorting out the secondary of the split-core transformer with the range switch. Leads are then connected to the voltage terminals. This is convenient for measuring both current and voltage because of the use of multiplier resistors and the rectifier. The usual ranges are 0 to 15, 60, 160, 600 amperes A-C and 0, 150, 600 volts A-C. The operational frequency-range is 50 to 70 cycles and accurate to within 5 percent.

5.17 Before taking any reading, be sure the meter pointer, while at rest, is at the zero point on the scale. If it is not, the zero meter adjust screw, usually located near the bottom of the meter window, should be reset to bring the pointer to zero. Turn the zero adjust screw clockwise or counterclockwise, whichever brings the pointer to zero, and then back off slightly to relieve the setting pressure from the pointer.

5.18 There is also a D-C hook-on ammeter, which is manufactured with a split-core of magnetic material. This instrument has an opening in the bottom section for the insertion of different D-C meter movements depending on the range needed. The instrument is similar to other hook-on instruments, but the meter movements are encased and detachable. The movements may differ in size as the type and marking of the scales change. This type instrument has only limited application.

Operating Principles of the Split-Core Instrument

5.19 A circular magnetic field is set up in the ring when the magnetic ring split-core is clamped around the current-carrying conductor. The strength of the magnetic field is proportional to the load current, and the torque developed in the instrument movement is proportional to the strength of the magnetic field. This meter has limited accuracy and it is adversely affected by stray magnetic fields or masses of iron or steel.

5.20 Clamp-on meters require no maintenance other than occasional cleaning of the window that covers the scale. Like any piece of precision test equipment, clamp-on meters require a reasonable degree of care in handling and use. Specifically, unnecessary jolts should be avoided. They can damage the meter movement.

Use these programed exercises to help check your learning progress.

5-1. The most important consideration when selecting a meter for electrical measurements is the type of _____ it will be used with.	5-1. CURRENT (A-C or D-C) REF: 5.01
5-2. When measuring alternating current and voltage, the meter that provides the most accurate indication is a meter that has an _____ movement.	5-2. ELECTRODYNAMOMETER REF: 5.02
5-3. A very common and useful portable instrument for electrical maintenance work is the _____-_____ meter.	5-3. SPLIT-CORE REF: 5.03
5-4. Split-core meters have been developed for situations where it is not desirable to open the circuit to take _____ measurements.	5-4. CURRENT REF: 5.05
5-5. Looping conductors through the core of a clamp-on meter is a method of _____ _____.	5-5. RANGE CHANGING REF: 5.12
5-6. When a clamp-on meter is used to measure voltage, _____ _____ must be used.	5-6. TEST LEADS REF: 5.13
5-7. When measuring A-C voltage with a clamp-on meter, the range switch shorts out the split-core _____ _____.	5-7. TRANSFORMER SECONDARY REF: 5.16
5-8. Split-core instruments have limited accuracy, and they are adversely affected by stray _____ _____.	5-8. MAGNETIC FIELDS or masses of iron or steel REF: 5.19

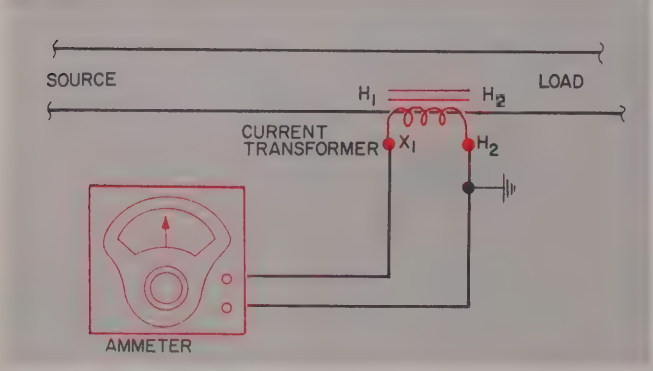
5.21 Instrument transformers perform two primary functions: (1) They isolate instruments, relays, and meters from line voltage. (To make this protection complete, the secondary circuit should be grounded at one point and the transformer case should also be grounded to that same point.) And, (2) they transform the line current or voltage into values suitable for measurement by standard instruments. Normal ratings of secondaries are 5 amperes for current transformers and 120 volts for potential transformers.

5.22 The primary winding of a current transformer is connected in series with the line current to be measured or controlled, as illustrated in Fig. 5-6. The primary winding of a potential transformer is connected across the line voltage to be measured, as illustrated in Fig. 5-7.

5.23 The secondary windings deliver current or voltage, respectively, with acceptable accuracy for operation of measuring instruments or control relays. An instrument transformer is either a current transformer or a voltage transformer. Both are applicable for measurement and control purposes.

5.24 Instrument transformers serve to separate measurement and control devices from line voltage and permit these devices to have a single rating for current or voltage. For measurement purposes, high accuracy is important; but for the operation of control and protective devices, only moderate accuracy is sufficient, while reliability and ruggedness are of the greatest importance.

Fig. 5-6. An ammeter and current transformer circuit connection.



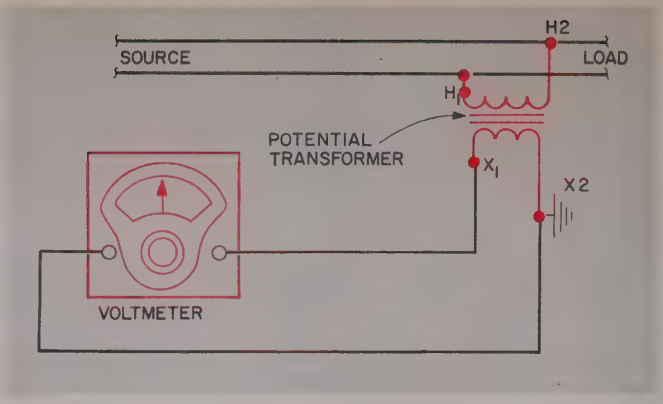


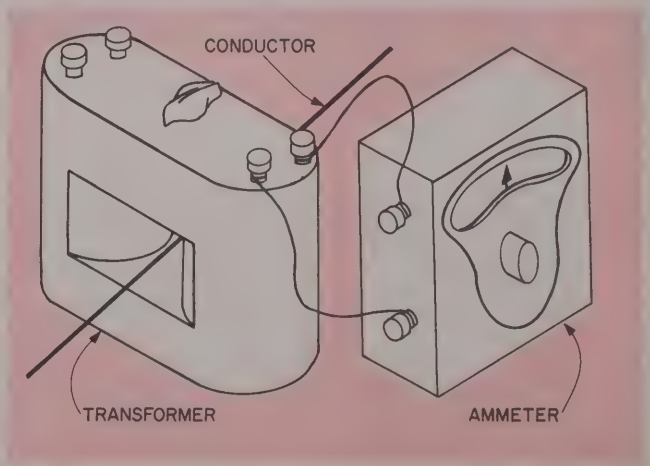
Fig. 5-7. A voltmeter and voltage transformer circuit connection.

5.25 The "ratio" in a current or voltage transformer is the ratio of the primary current (or voltage) to the secondary current (or voltage), under specified conditions.

CAUTION: Do not directly connect measuring instruments and high voltage circuits. Because of the delicate nature of the instruments, they may be damaged by high voltages.

5.26 A current transformer is used to connect ammeters and the current coils of instruments to lines carrying high current. One type of current transformer is so constructed that the conductor, in which current is to be measured, can pass directly through an opening in the transformer assembly, as illustrated in Fig. 5-8. The conductor thereby becomes the primary of the transformer, even though only a short length of it passes through the assembly. The secondary consists of a winding with many turns within the transformer assembly, and the measuring instrument is con-

Fig. 5-8. Portable current transformer and ammeter.



nected to the secondary. In large conductors, there are no electrical connections between the transformer and the large conductor. In current transformers for small conductors, a primary winding within the transformer housing is often connected in series with the conductor.

5.27 A voltage transformer is used to connect voltmeters to A-C circuits carrying high voltages. These transformers are similar to the constant-potential transformers used for power circuits, except that the power rating of instrument voltage transformers is always low. Voltage transformers are available in a dry type and an oil-immersion type, depending on their maximum voltage rating. Their primaries may be rated for voltages of 35,000 volts, and their secondaries rated at 120 volts.

5.28 For relatively high current ranges, the primary often consists of one or more turns of a conductor passing through the center of the current transformer. For example, in the case of one turn, the ratio could be 800 : 5, two turns, 400 : 5, etc.

CAUTION: Standard operating procedures for current transformer safety require that the secondary winding ALWAYS be SHORTED or CONNECTED to the ammeter. Otherwise dangerous potentials may occur at the secondary terminals of the transformer.

5.29 Insulation protection between primary and secondary windings is usually sufficient for several times the maximum rated voltage of the transformer.

5.30 Current and potential transformers extend the applications of A-C instruments in the same way as shunts and series resistors extend the applications of D-C instruments.

Design of Current Transformers

5.31 Although the designs of current transformers are necessarily based on the same fundamental principles as those of power transformers, the conditions under which they operate (nearly short-circuited secondary and varying terminal voltage), are so special that the resulting designs are quite different. Flux density under normal conditions is very low. Ampere-turns at rated primary current are at least 1000 for good accuracy, under normal conditions, if silicon steel is used. In high-range current transformers, this requirement is met by the use of a single primary conductor running through the center of the core opening. This transformer, when subjected to severe overloads, exhibits no mechanical force, which would tend to distort the primary.

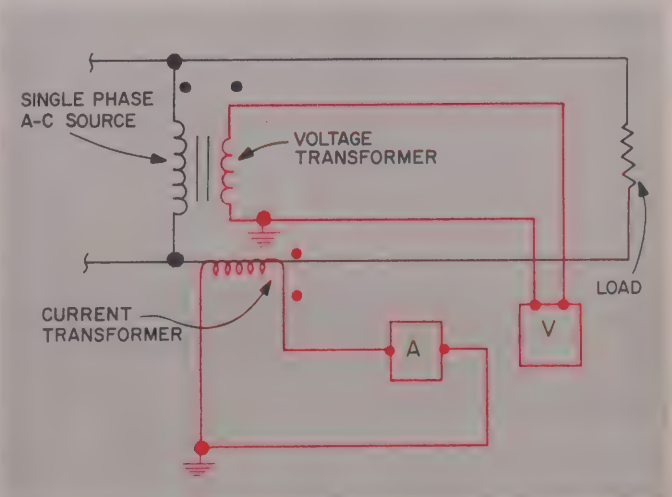
Polarity Markings

5.32 It is important that the primary terminals and secondary terminals of instrument transformers be marked so that when a lead is connected to a terminal marked SECONDARY, the polarity will be the same as the primary conductor running to the terminal marked PRIMARY. In a wiring diagram, primary and secondary terminals having the same instantaneous polarity are usually marked with a dot, as illustrated in Fig. 5-9. The relationship of the marked terminals is such that if the instantaneous direction of the current in the lead marked PRIMARY is TOWARD the transformer, the instantaneous direction of current in the lead marked SECONDARY is AWAY from the transformer.

Testing Current Transformers

5.33 It is also possible for the transformer windings to be damaged by surges, overloads, or other disturbances. It is therefore good practice to conduct tests at the time of installation and every five years thereafter on all instrument transformer used in important metering installations.

Fig. 5-9. Connecting instrument transformers.



5.34 If the core of a current transformer becomes permanently magnetized by the passage of direct current through its windings, or by the opening of its secondary circuit while primary current is flowing, the ratio may be seriously changed. The original values may be restored by DEMAGNETIZING THE CORE. This is conveniently done by sending an alternating current of 5 amperes through the secondary winding while the primary is open, and gradually reducing this current to zero. An alternate method is to send rated current through the primary winding while the secondary is connected to a resistance of several hundred ohms, and then gradually reduce this resistance to zero.

Overload Designs

5.35 When a short circuit occurs in the line around which a current transformer is coupled, the primary current may momentarily attain many times its rated value. One design of the primary winding is such that the transformer is not damaged by the mechanical or thermal effects of moderate overloads. Another design is used when the operating loads are such that the transformer core is near its saturation point with normal operating currents. The secondary current does not increase in proportion to the primary current. Such a characteristic is desirable, because secondary instruments and relays are thus spared much of the shock of any short circuit. The increase in secondary current is enough to cause the relays to maintain the ratio reasonably constant even on severe overloads. Transformers may be designed to have either type of characteristic.

5.36 It is sometimes best to measure the current in a cable without cutting it to insert the primary winding of the current transformer. This can be done by the use of a current transformer that has its core made in two parts, hinged together, and provided with a secondary winding. This transformer resembles an oversized doughnut. Although not capable of very great accuracy, such transformers are useful for approximate measurements. For example, the current taken by large motors, and the distribution of load among transformer banks in parallel.

5.37 Many portable current transformers and

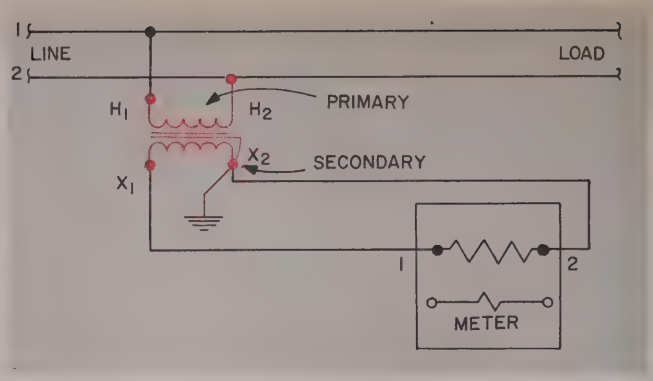


Fig. 5-10. Single-phase current and voltage transformer connections.

certain types of switchboard transformers are provided with two or more sections of primary winding which can be connected in series or in parallel to give various primary ranges. The use of these switchboard transformers makes it possible to take care of growth at the plant load centers without replacing the instrument transformers.

5.38 Certain special types of current transformers are made with duplicate cores and duplicate secondary windings, which are placed in a common oil tank and linked to the same primary winding. Such "double-secondary" transformers constitute, in effect, two transformers, one of which can be used with a light load for accurate metering, while the other supplies relays or other control equipment of higher loads. This construction avoids duplication of the expensive high-voltage "bushing" (insulation) and the oil tank.

Grounding

5.39 The primary of a voltage transformer is not normally grounded independent of the system.

5.40 It is standard practice to ground the common or neutral secondary wire or wires at the transformer. Figure 5-10 illustrates normal grounding of a single-phase secondary. Secondary grounding is necessary to prevent a high static potential in secondary leads and as a safeguard in case of insulation failure, which can cause high voltage to appear on the secondary leads. The transformer case should be grounded for the same reason. There should be only one ground on the circuit, preferably at the transformer. Do NOT ground the circuit at more than one point. Use extreme caution around the circuit so *you* yourself don't complete a path to ground.

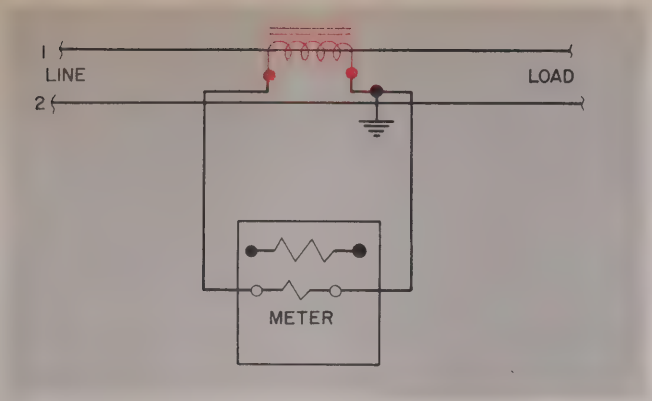


Fig. 5-11. Two-wire, single-phase meter connections.

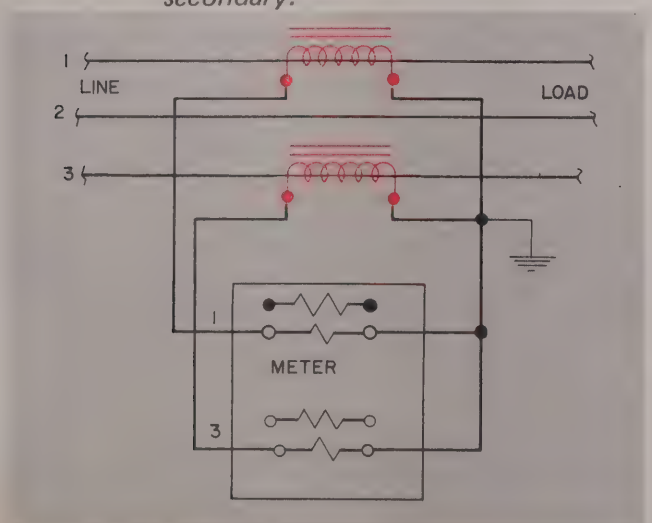
Fusing of Instrument Voltage Transformers

5.41 PRIMARY FUSES – the use of primary fuses on a voltage transformer protects the transformer from damage because of high-voltage surges, and fuses protect the system from an outage caused by failure of the transformer. To do this, the fuse must be of very small current rating, because the normal primary current of a potential transformer is very small.

5.42 If a primary fuse opens for any reason, the load will be incorrectly metered until the fuse is replaced.

5.43 SECONDARY FUSES – the secondary leads of a voltage transformer are often fused. The secondary fuses protect transformers from short circuits in the secondary wiring. Fuses and fuse clips, however, may introduce sufficient resistance into the circuit to cause metering errors. Where

Fig. 5-12. Three-wire, three-phase, three-wire secondary.



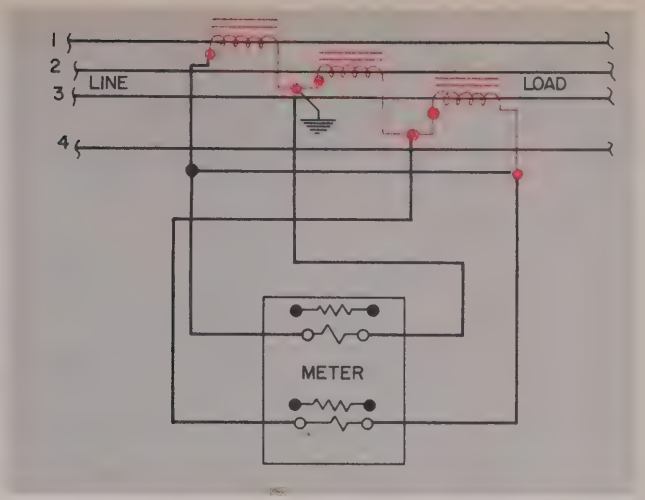


Fig. 5-13. Four-wire, three-phase with delta-connected secondaries.

corrosion is present this effect may become serious, therefore metering circuits should be checked periodically.

Current Transformer Connections

5.44 Single-Phase Two-Wire connections are illustrated in Fig. 5-11, with the connections for one current transformer supplying single-phase current to the current coil of a meter. Note that the non-polarity-marked secondary lead at the transformer is grounded.

5.45 The Three-Wire, Three-Phase connections in Fig. 5-12 illustrate one method of measuring three-phase current.

5.46 Figure 5-13 illustrates the connections used to normally provide a three-wire current measurement from a four-wire system. This setup is frequently used for indicating and graphic-recording meters, relays, and some watthour meter readings. The metering is theoretically correct only at balanced voltages, but on most power systems the voltage is normally balanced well enough to give acceptable accuracy. Figure 5-14 illustrates a typical connection for three-phase voltage measurement.

Safety Precautions in Testing Instrument Transformers

5.47 All instrument transformer testing involves high voltage hazards. Voltage transformers, by their very nature, are high-voltage devices and

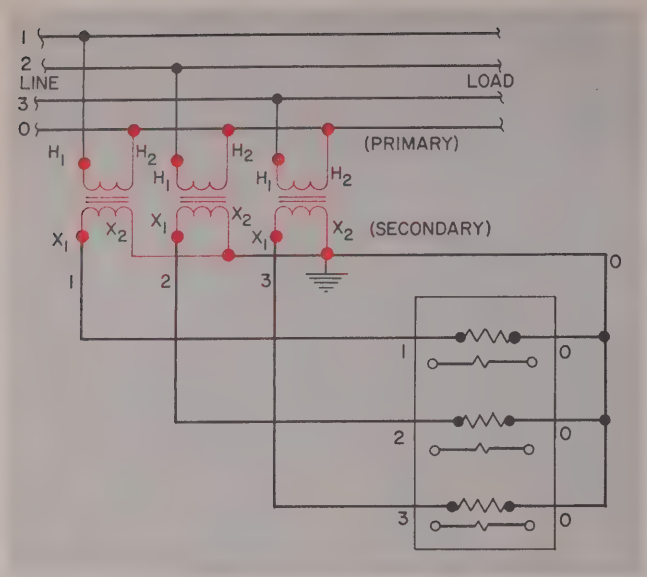


Fig. 5-14. Three-phase, four-wire, wye-wye, four-wire secondary.

current transformers can develop DANGEROUSLY high voltages if the secondary is accidentally opened under load. No one should be allowed to make tests on instrument transformers until he has been thoroughly instructed on the hazards and proper safety precautions.

5.48 Many safety devices are provided: safety tapes, warning lights, interlocking foot switches, test enclosures with interlocking gates, and double switches, which require two-hand operation. But these safety devices can never be made absolutely foolproof. The responsibility for safety ultimately rests with the man making the tests. For your own protection, use caution, care, and good commonsense.

5.49 When testing current transformers, it is particularly important to make all secondary connections mechanically secure, so that even a strong pull on the test leads cannot open the circuit. For this reason, spring test clips should NEVER be used on current transformer secondary test leads. Only a solidly screwed or bolted connection can prevent an accidental opening of the secondary circuit, and the consequent high voltage hazard.

WARNING: The secondary of any current transformer should NEVER be left open circuited under any circumstances while the primary is energized.

5.50 The metal cases of instrument voltage transformers and one secondary test lead should be solidly grounded as a protection from high static voltages and against the danger of a high-voltage breakdown between primary and secondary. All metal-clad test equipment should also be grounded.

5.51 The polarity markings, usually a white dot, should always be checked before making or changing any connections. Remember that the fundamental responsibility for safety lies with the electrician, who must use the utmost care to deenergize the equipment before approaching any unknown or suspected high-voltage terminals. You must never fall into the bad habit of depending upon the interlocks, as interlocks can fail.

REMEMBER: The life you protect may be your own.

5-9. Current transformers are designed to operate under near _____-_____ secondary conditions.	5-9. SHORT-CIRCUITED REF: 5.31
5-10. Instrument transformer primary or secondary terminals having the same instantaneous polarity are marked with a _____.	5-10. DOT REF: 5.32
5-11. It is good practice to conduct tests on instrument transformers, in accordance with the manufacturer's instructions, every _____ years.	5-11. FIVE REF: 5.33
5-12. Double secondary transformers are sometimes used to supply a dual load. They meter from one secondary and supply _____ loads from the other. *(greater/lesser)*	5-12. GREATER loads such as relays or other control equipment REF: 5.38
5-13. The primary of an instrument voltage transformer is NOT normally _____ independently.	5-13. GROUNDED REF: 5.39
5-14. Primary fuses, when used in an instrument voltage transformer, must be of a very _____ rating. *(large/small)*	5-14. SMALL because primary current is small REF: 5.41
5-15. If a primary fuse should open, the load will be _____ metered until the fuse is replaced.	5-15. INCORRECTLY REF: 5.42
5-16. The metal cases of instrument voltage transformers, and one secondary of each transformer, should be solidly _____.	5-16. GROUNDED as a protection against static and high voltage breakdown REF: 5.50

BRIDGE CIRCUIT – A network in which the instrument or the load is bridged across the intermediate points of two parallel elements across which an input voltage is applied.

DAMPING MAGNET – A permanent magnet associated with a metal vane that is attached to the moving member of an instrument to produce eddy currents in the vane, which causes damping of the moving element.

MULTIRANGE INSTRUMENT – An instrument that can be used for measuring two or more ranges of measurement.

PHASE ANGLE (Electrical) – The difference in the phase relationship of current and voltage when expressed as the angle between the vectors of current and voltage.

POTENTIAL TRANSFORMER (Instrument) – A transformer intended for measurement or control purposes and designed to maintain a substantially constant ratio between the primary and secondary voltages. The primary winding is connected in parallel with the circuit voltage being measured or controlled. The ratio of the transformer is such that an instrument connected to the secondary can be calibrated in terms of the primary voltage.

CURRENT TRANSFORMER – A transformer intended for measurement or control purposes and designed to carry the full current of the measured circuit in its primary winding. The ratio of the transformer is such that a low-rated instrument connected to the secondary can be calibrated in terms of the primary current.

PRIMARY WINDING (Instrument transformer) – The winding which is connected to the measured circuit.

SECONDARY WINDING (of an instrument transformer) – The winding to which the indicating or recording instrument is connected.

SPLIT-CORE TRANSFORMER – A transformer that has its core constructed so the magnetic structure can be opened and closed.

POTENTIOMETER (Instrument) – A device in which the deflection of the indicating element can be controlled by a fixed element. The indicating element is calibrated in terms of the quantity being measured. The network includes adjustable elements to balance the indicating element to a zero reading.

RECTIFIER – A device for changing alternating current to direct current by permitting a flow of current in only one direction during each alternation.

ROOT-MEAN-SQUARE (rms) – The effective value of an A-C quantity. The square root of the average of the squares of all instantaneous values of the quantity when taken through one complete cycle.

SCALE DISTRIBUTION – The arrangement of the scale graduations with respect to the magnitude of the quantity being measured.

ZERO ADJUSTER – A device for setting the pointer of an instrument to zero when no current is flowing.

ZERO POSITION – The position of the pointer of an instrument when no current is flowing.

SELF-CHECK QUIZ

5-1. A split-core meter must have its hinged core closed with a close fit when operating to ensure minimum

a. magnetic circuit reluctance
b. induced currents
c. voltage loss
d. meter resistance

5-2. Looping the conductor through the core of a split-core meter will decrease the instrument's

a. transformer ratio
b. current rating
c. magnetic induction
d. total resistance

5-3. To allow the split-core instrument to be used as a voltmeter, it has an internally-connected

a. inductance converter
b. potential transformer
c. resistor and rectifier network
d. magnetic bypass circuit

5-4. Closing the jaws of a clamp-on meter around the conductor when taking voltage readings would likely cause

a. a short circuit
b. an erroneous reading
c. reversed pointer indication
d. severe damage to the meter

5-5. The accuracy of a split-core meter is adversely affected by

a. high resistance
b. circuit impedance
c. stray magnetic fields
d. magnetic shielding

5-6. What maintenance is required for split-core meters?

a. Calibration annually
b. Demagnetization
c. Even-temperature storage
d. Occasional cleaning of the scale window

5-7. For proper protection, all instrument transformer secondaries should be

a. center-tapped
b. grounded
c. short-circuited
d. used at a low potential

5-8. The secondary of a current transformer should NEVER be open-circuited because of high

a. primary current
b. secondary current
c. primary voltage
d. secondary voltage

5-9. When connecting instrument transformers, it is standard practice to ground the

a. primary neutral or common
b. secondary neutral or common
c. center-tap terminal
d. unbalanced phase

5-10. When testing instrument transformers, the responsibility for personnel safety rests with the

a. interlocking devices
b. warning lights
c. instrument repair supervisor
d. man making the tests

ANSWERS TO SELF-CHECK QUIZ

5-1. a. Magnetic circuit reluctance. REF: 5.09.

5-2. a. Transformer ratio. REF: 5.12.

5-3. c. Resistor and rectifier network. REF: 5.12.

5-4. b. An erroneous reading. REF: 5.13.

5-5. c. Stray magnetic fields. REF: 5.19.

5-6. d. Occasional cleaning of the scale window. REF: 5.20.

5-7. b. Grounded. REF: 5.21.

5-8. d. Secondary voltage. REF: 5.28 (Caution:).

5-9. b. Secondary neutral or common. REF: 5.40.

5-10. d. Man making the tests. REF: 5.48.

LESSON SIX

POWER MEASURING INSTRUMENTS

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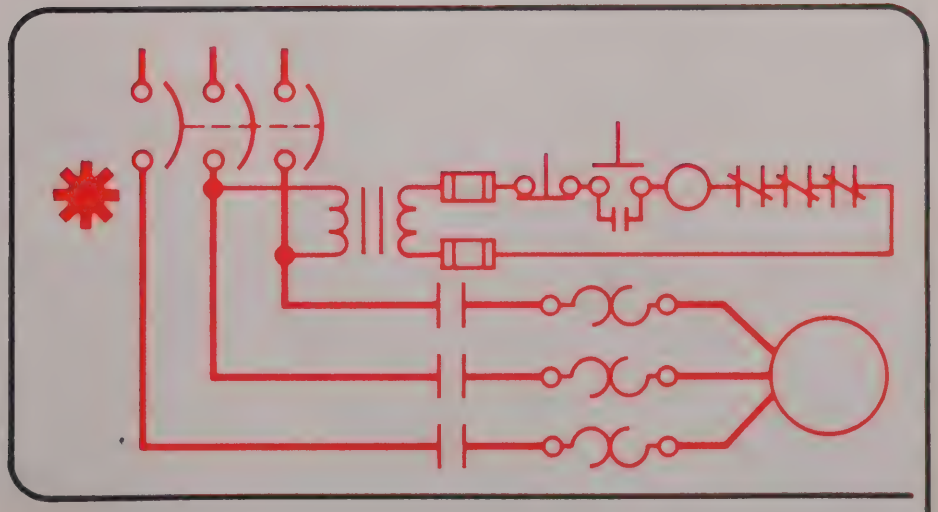
Electrical Measuring Instruments



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Lesson Six — Power Measuring Instruments

Preface

Electrical power can be measured in direct-current circuits by measuring the current and the voltage of the load with an ammeter and voltmeter. The power is the product of the two.

In alternating-current circuits, the current through the load, the voltage across the load, and the power factor of the load, must be measured by an ammeter, voltmeter, and "power-factor meter," respectively. The power can be determined from these three variables. Electrical power can be measured, in both direct and alternating-current circuits, by means of a "wattmeter."

Electrical energy is not the same as power. Power is an instantaneous quantity; energy includes the time function or how long the power has been applied. Energy equals power multiplied by time; so when you want to measure energy, it is necessary to have a meter that will measure the amount of power used over a period of time. The basic unit of measurement for electrical energy is the WATTHOUR. As energy is the product of power and time, the "watthour meter" must take into consideration both of these factors.

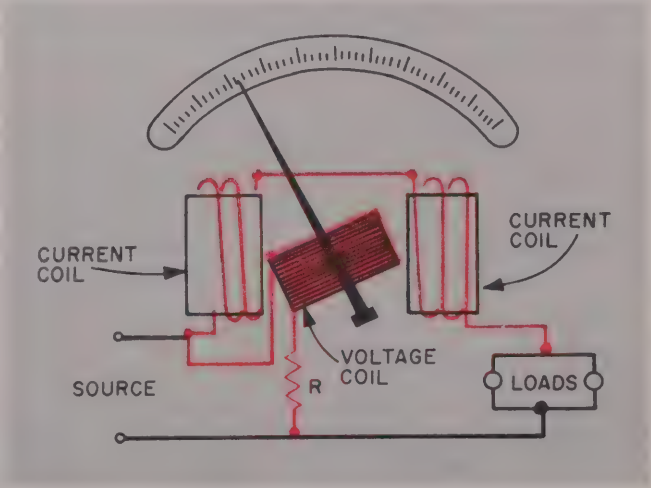
The power factor of a circuit can be determined by the use of a wattmeter, a voltmeter, and an ammeter — that is, the power factor can be determined by dividing the wattmeter reading by the product of the voltmeter and ammeter readings.

The operation of power-measuring instruments and their industrial applications are explained in this lesson.

Wattmeters

6.01 Electrical power is measured by a wattmeter. Electrical power is the rate at which electrical energy is used, and its unit of measurement is the watt. The watt implies the time factor "per hour," hence the term watt implies "watts per hour." Wattmeters usually have an electrodynamometer movement, which basically consists of a pair of current (fixed) coils and a pair of potential (movable) coils. The basic circuit for measuring single-phase or D-C power is illustrated in Fig. 6-1. (We will call the current, fixed coil-pair, the fixed coil; and the potential, moving coil-pair, the moving coil.)

Fig. 6-1. Basic circuit components in a wattmeter.



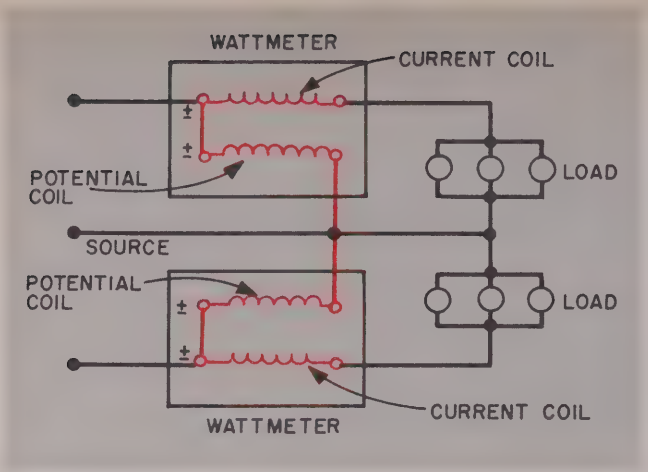


Fig. 6-2. Polyphase wattmeter connections for a 3-wire circuit (either balanced or unbalanced load conditions).

6.02 The moving coil is mounted on pivots and jeweled bearings, and it turns freely in the magnetic field of the fixed coil. The moving coil is connected to the line voltage; the fixed coil carries a current proportional to line current. The torque exerted on the moving coil is balanced by spiral springs. A pointer fastened to the moving coil indicates the average power. Flat coil springs hold the needle to a zero position. The fixed coil is connected in series with the load, and the moving coil is connected across the line.

6.03 When line current flows through the fixed coil of a wattmeter, a field is set up around the coil. The strength of this field is proportional to the line current and in phase with it. The moving coil of the wattmeter generally has a high resistance connected in series with it. This makes the moving-coil circuit almost purely resistive. As a result, current in the moving-coil circuit is practically in phase with line voltage. Therefore, when voltage is impressed on the moving-coil circuit, current is proportional to, and in phase with, the line voltage.

6.04 The force that causes a wattmeter to operate is obtained from the interaction of the field of its current coil with the field of its potential coil. The force that tends to turn the movable coil at any instant is therefore proportional to the product of the instantaneous values of line current and voltage.

CAUTION: Use wattmeters within their VOLTAGE and AMPERE ratings. Unlike ammeters and voltmeters, wattmeters can be damaged from overload, without any prior warning, if too much current or voltage is applied to the coils. If an ammeter or voltmeter is overloaded, the pointer attempts to register the overload. But, because the wattmeter indicates power rather than current or voltage, the pointer operates normally, although the coils may be overheating. A low power-factor circuit will give a low reading on the wattmeter even when the current and voltage circuits are at, or over, the rated limit of the meter. Figure 6-2 illustrates how a wattmeter should be connected.

6.05 Where the load is purely resistive, current is in phase with voltage and the circuit has a unity power factor. Instantaneous value, then, of power, or watts, is the product of the instantaneous current and instantaneous voltage. Although both current and voltage are negative during one-half of each cycle, their product is always positive.

6.06 All industrial loads are not purely resistive, however. For instance, a motor has coils that are embedded in iron or steel, which introduces inductive reactance into the circuit. The current required to magnetize this iron will lag the impressed voltage by 90 electrical degrees. The greater this magnetizing current, the farther away the resultant current will be from the in-phase position. In theory, when total current is 90 degrees out-of-phase with the voltage, there is no power (or watts) consumed. Therefore, the product of voltage and current is NOT, in a REACTIVE circuit, a measure of power being used. Field flux is proportional to line current, while armature flux is proportional to line voltage.

6.07 The instantaneous torque (or turning effect) of the moving coil is proportional to the instantaneous product of line current and voltage. Since the moving system's inertia does not allow the pointer to indicate each instantaneous power value, the average power is indicated on the instrument scale.

Wattmeter Ratings

6.08 Wattmeters are rated not only in watts, full-scale deflection, but also in amperes and volts. Ampere ratings indicate the maximum current to be passed through the current or fixed coil. On the

other hand, voltage ratings show the range of potential circuit voltages for which the instrument is designed. Hence a wattmeter having a 5-amp current rating will have a full-scale rating of 250 watts at 50-v; 500 watts at 100-v; 1000 watts at 200-v.

6.09 Power measurements involving high current are made in conjunction with a current transformer. In those cases, the wattmeter current rating is usually 5 amps.

6.10 For example, when you measure power in a circuit having a low power factor, such as a single-phase load pulling 8 amps at 200 volts and a power factor of 0.6, the wattmeter reads 960 watts.

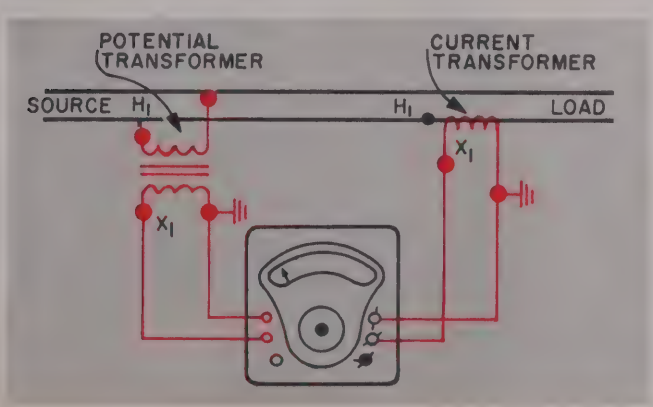
Power = E x I x PF = 200 x 8 x 0.6 = 960 watts

This is 40 watts short of scale maximum. But in the meantime, 160 percent of rated current is flowing through the instrument. (8 amps = 1.6 x 5 amps-meter maximum current.) The voltage and current maximum ratings of the instrument being used must be considered.

6.11 For potentials up to 750 volts, series resistors are often used in the armature circuit of many wattmeters. When higher voltages are present, a potential transformer is used.

NOTE: When a wattmeter is used with a current or potential transformer, or both, as illustrated in Fig. 6-3, include all multiplying factors. For example, if the current-transformer ratio is 5:1 and the potential-transformer ratio is 4:1, the multiplying factor is 20. In other words, if the wattmeter reads 10 watts on its scale, it should be multiplied by 20. The actual power being consumed by the load would be 200 watts.

Fig. 6-3. Connections of wattmeter with instrument transformers.



6.12 Wattmeters are more necessary in A-C measurements than in D-C. With D-C, watts equal volts multiplied by amperes, and you can get along without a wattmeter. In A-C circuits, however, there are occasions in which watts do not equal volts multiplied by amperes, but a wattmeter will still indicate the power consumption in the circuit.

Measurement of Three-Phase Power

6.13 Power in a three-wire, three-phase system is usually measured with a three-phase wattmeter. When one is not available, three-phase power can be measured with two single-phase wattmeters. The phases of the loads do not have to be balanced.

6.14 The three-phase wattmeter essentially consists of two single-phase wattmeters with the moving elements mounted on a common shaft. A single pointer shows the total power; the instrument itself makes the necessary addition or subtraction of the two readings automatically and correctly, provided the connections have been correctly made. The wiring diagram furnished with the instrument must, therefore, be strictly followed in making connections. The polarity marks on instrument transformers show the relative direction of instantaneous current flow in the primary and secondary circuits. They are needed to make correct connections to a three-phase wattmeter.

Watthour Meters

6.15 The WATTHOUR meter is an instrument that is used to measure electrical energy. In principle, the watthour meter is a small induction motor whose instantaneous speed is proportional to the POWER passing through it. The total revolutions in a given time are proportional to the total ENERGY or watthours consumed during that time.

6.16 A wattmeter and a watthour meter have relatively the same relationship to each other as do the speedometer and the odometer on an automobile. A speedometer indicates miles per hour. A

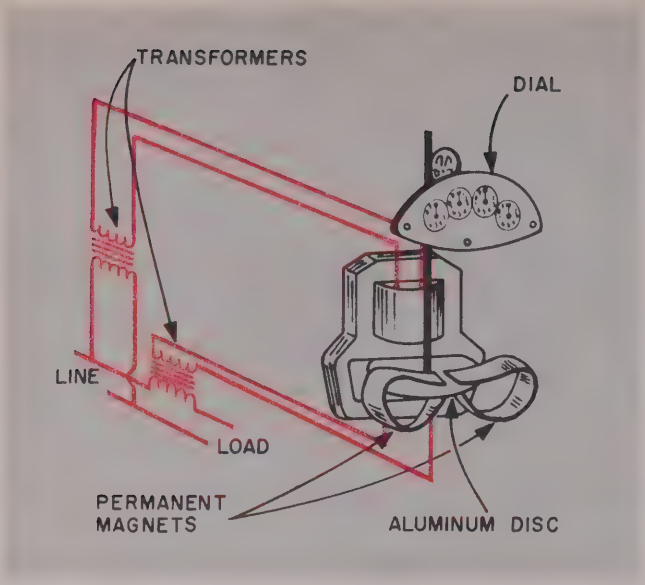


Fig. 6-4. Circuit components of a watthour meter.

wattmeter indicates watts, and watts per hour equals watthours. An odometer shows the total number of miles traveled. A watthour meter measures the total watthours that have been used. Just as an odometer will indicate 60 miles, for example, after a car has traveled two hours at a speedometer indication of 30 miles per hour, a watthour meter will indicate 1000 watthours if connected for two hours in a circuit using 500 watts. Figure 6-4 illustrates the basic operating circuits of a watthour meter.

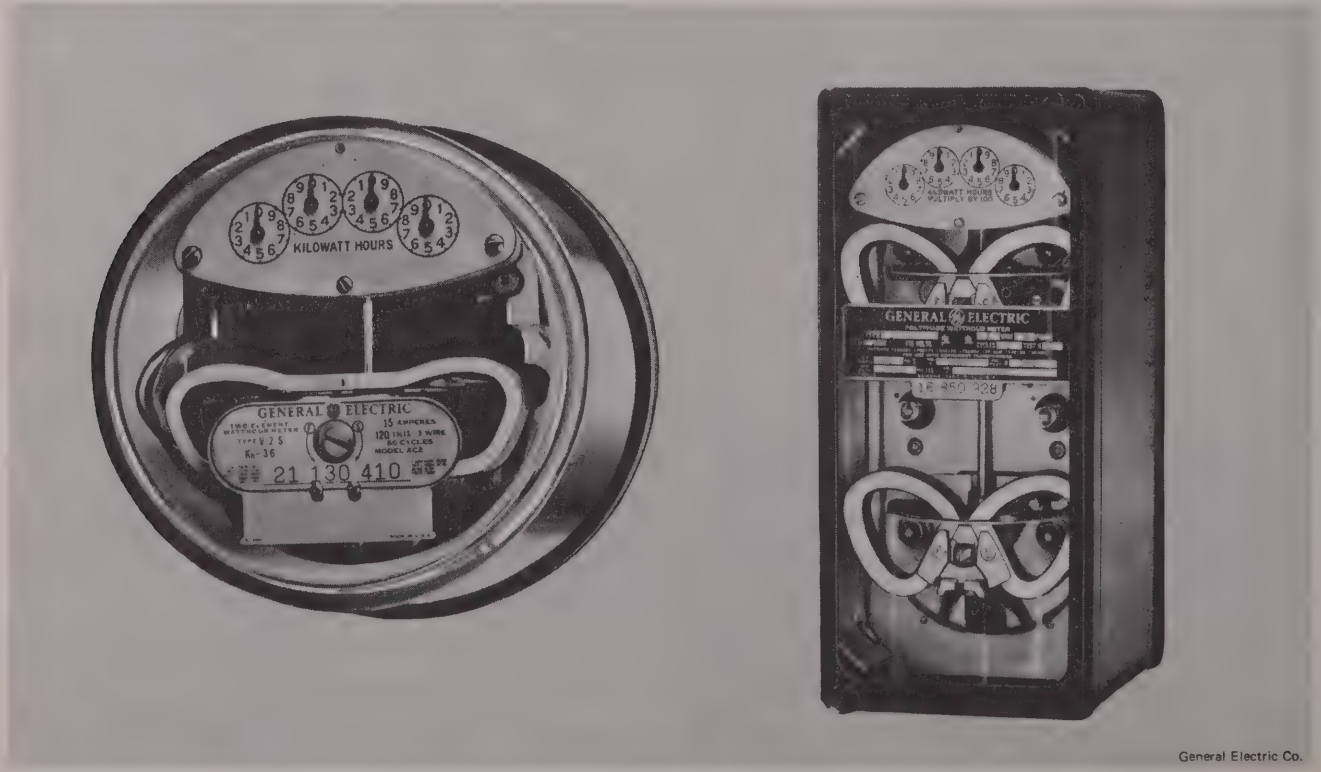
How to Read a Watthour Meter

6.17 There are usually four dials on the watthour meter with each dial marked from 0 to 9, as illustrated in Fig. 6-5. Since the most practical unit of measurement is in terms of thousands of watthours, the watthour meter readings on the four dials read in "kilowatthours" (KWH). One kilowatt is equal to 1,000 watts. Stated in other words, one kilowatthour is the energy expended at the rate of one kilowatt (or 1,000 watts) over a period of one hour. The kilowatthour is the unit of work or energy that comes through the electrical service wires.

6.18 The reading on the first dial on the right of the watthour meter registers the number of single units. Each dial-pointer must complete a revolution to advance the dial-pointer located to its left one division. Therefore, in reading a dial, the dial before it (to the right) must be consulted. Unless that pointer has reached or passed 0 (that is, completed a revolution), the pointer in question has not completed the division on which it may appear to rest. For this reason, read the meter from right to left for accuracy.

6.19 It is comparable to reading a watch. When the hour hand is near 8 and the minute hand is at

Fig. 6-5. Typical polyphase watthour meters.



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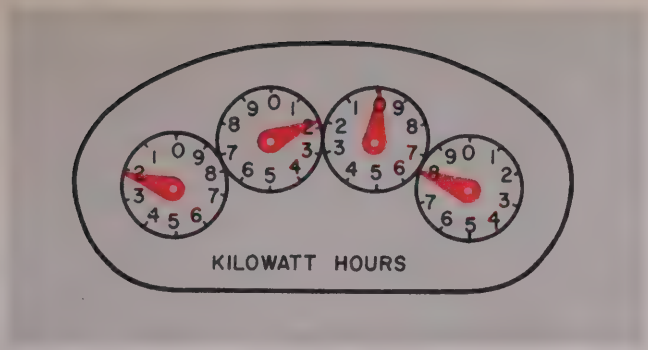


Fig. 6-6. Kilowatthour dial showing reading of 2198 kilowatthours.

11, it is not yet 8 o'clock, but 7:55, and it will not be 8 o'clock until the minute hand has advanced to 12. Figure 6-6 illustrates a typical kilowatthour dial and its reading.

6.20 The speed of the induction motor in a watthour meter is proportional to the power in the metered circuit. In addition to the motor, a watthour meter has a magnetic braking system and a register (or dial).

6.21 The rotor you see turning in a watthour meter is an aluminum disk. And the worm gear that drives the register is usually assembled on a shaft and connected to this rotor. Bearings can be of the jewel and pivot or ball bearing types. The rotor may be magnetically suspended. (In this case, guide pins maintain vertical alignment of the shaft.) In either case, the moving system is so mounted that the aluminum disk is centered in the air gap of the laminated assembly. This aluminum disk provides a damping effect for the moving system as a result of magnetic induction.

6.22 The stator for the motor, sometimes known as the element, is an electromagnet which has two sets of windings. One winding, called the potential coil, is connected across the metered circuit. The other winding – the current coil – is connected in series with the load. The potential coil is made up of fine wire and has a high resistance. It places a negligible load on the circuit. The current coil has relatively few turns of larger wire. This element is basically the same as the electrodynamometer previously explained. To obtain accurate results, connections must always be made in strict accordance with the wiring diagram furnished with the instrument.

Use these programed exercises to help check your learning progress.

6-1. A wattmeter measures electrical power by using a meter mechanism called an _____.	6-1. ELECTRODYNAMOMETER REF: 6.01
6-2. The operating forces for a wattmeter are a result of interaction of the fields generated by its _____ and _____ coils.	6-2. CURRENT and POTENTIAL REF: 6.04
6-3. Wattmeters must be used ONLY within their proper _____ and _____ ratings.	6-3. VOLTAGE and CURRENT REF: 6.04
6-4. If a three-phase wattmeter is not available, power in a three-phase system can be measured with _____ _____-_____ wattmeters.	6-4. TWO SINGLE-PHASE REF: 6.13
6-5. A watthour meter measures the total _____ consumed during a period of time.	6-5. ENERGY REF: 6.15
6-6. A watthour meter will usually have _____ dials with each dial marked from _____ to _____.	6-6. FOUR, 0 to 9 REF: 6.17
6-7. For accurate readings, watthour meter dials should be read from _____ to _____.	6-7. RIGHT to LEFT REF: 6.18
6-8. In a watthour meter, the aluminum disk provides _____ for the worm gear drive mechanism.	6-8. DAMPING REF: 6.21

Varmeters

6.23 In alternating-current circuits with a resistance type load, all power flowing in the lines is consumed in the load. In alternating-current circuits that are not purely resistive, some power known as "reactive power" is delivered to the circuit during part of the cycle and returned to the source during another part of the cycle. This reactive power does no useful work at the load but increases the current in the circuit and results in increased losses and poorer voltage regulation. This reactive power is measured by varmeters.

6.24. It is common to have a condition where vars, which do no useful work, are equal to the watts. This is one reason why overloaded feeders occur. Many industrial plants have installed capacitors or synchronous motors to compensate for this condition. However, the varmeter is an important instrument to indicate how great the reactive currents are in a circuit.

6.25 The electrodynamometer element, in addition to being used to measure watts, has wide application in measuring reactive volt-amperes or vars. The wattmeter indicates the product of circuit voltage and the current component that is in phase with the voltage. The varmeter indicates the product of voltage and the current component that is 90 degrees out-of-phase with voltage.

6.26 This is done, in single phase measurements, by shifting the phase of the voltage across the instrument's potential coil. Thus the potential-coil flux is in phase with the flux produced by the reactive current component in the field coil.

6.27 Varmeters are similar in construction to wattmeters except that the current through the potential coil is shifted in phase with respect to the line voltage. This is accomplished in single-phase varmeters by connecting a reactor (inductance) in series with the potential coil, and in three-phase varmeters by cross connection of the potential coils.

6.28 The varmeter is actually a meter with built-in means of obtaining the 90-degree phase shift in which it measures the component. The meter may incorporate an internal capacitor-resistance unit or autotransformer, and it is installed in the same manner as a wattmeter.

6.29 Varmeters are usually calibrated in thousands of vars (kvars) or volt-amperes (kva). The principle purpose of kvar and kva metering (or phase-displaced metering, which is a term describing this entire category) is in its application to the measurement of one or more of the quantities involved: power factor, average power-factor, kva, and kva-hours (kvah).

Demand Meters

6.30 You may look upon a demand meter as a means for indicating a high plant load factor or a long steady operating hour factor. The meter may indicate a problem area when the demand is recorded, such as high peaks in conjunction with low kilowatthour consumption. The meter itself can be used to advantage in the plant by using its indication as a guide when peak-load periods come up.

6.31 Temperature buildup, which burns the insulation in electrical equipment, is the principal limiting factor in determining the amount of load that can be imposed on electrical equipment. The limiting temperature on insulating material is reached only if an overload is sustained for an appreciable period of time. That's the reason the power demand should be averaged over definite periods of time.

6.32 Watthour meters equipped with demand registers are referred to as WATTHOUR-DEMAND METERS and, with the exception of the register and deeper covers, are identical to watthour meters of corresponding type. Some of the terms used with demand metering, and their definitions, are as follows:

AVERAGED MAXIMUM DEMAND – Highest average or arithmetical mean of several similar demands. It may be computed from several demands on a definite number of days. These days may be either consecutive or within certain time limits, such as weeks or months.

DEMAND METER – Indicates or records the peak demand or the maximum demand at given time periods.

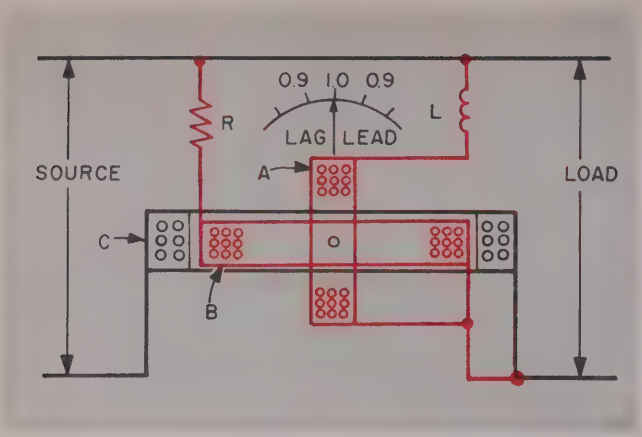


Fig. 6-7. Power-factor meter operating-mechanism.

DEMAND INTERVAL – Period of time in which demand is measured.

DEMAND – Load averaged over a specified period of time. Demand is expressed in kilowatts, kilovolt-amperes or amperes.

MAXIMUM DEMAND – Greatest quantity of all demands that have occurred during a given period.

LAGGED-DEMAND METER – Where maximum demand indication is subject to a characteristic time lag.

6.33 Demand readings, or consumption measurements, are usually in terms of either kilowatts, kilovolt-amperes, or kilovars, the quantity being indicated on the dial face or the nameplate of the instrument. The demand meter may be incorporated within a watthour meter, it may be associated with a separate watthour meter, or it may be independent of any watthour meter, which makes it a separate demand meter. Demand readings may be either indicating or recording. In reading a demand meter, it is important that the reading be taken directly in front of the meter. This is to avoid parallax errors.

Power-Factor Meters

6.34 A POWER-FACTOR METER indicates the power factor continuously, and at the same time indicates whether the current is leading or lagging the voltage.

6.35 In alternating-current circuits, the power flowing in the lines is made up of two parts: (1) useful power, which is expended in the load, and (2) reactive power, which flows back and forth, thus contributing to the load carried by the conductors but serving no useful purpose. Remember the ratio of useful power to the apparent power is called the circuit power factor.

6.36 Hence the operation of power-factor meters depends on the interaction between a pulsating, single-phase magnetic field produced by a single coil, and a rotating magnetic field produced by two or more other coils. The moving element may be the single coil, the other coils, or an iron-vane magnetized by the single coil.

Power Factor Measuring Instruments

6.37 At the instant that the pulsating, single-phase field is at its maximum value, the moving coil assumes a position that is aligned with it. Both single-phase and three-phase power-factor meters are in common use. The circuits for the operating components of a typical power-factor meter are illustrated in Fig. 6-7.

6.38 Circuit continuity to the coils is provided by three spiral springs that exert negligible restraining force on the coils. Therefore, when no current flows through the coils, the pointer may come to rest at any position on the dial. Coil C (not drawn to scale) is connected in series with the line. In most installations the coils are energized through instrument transformers, and the currents are proportional to line values.

6.39 The power-factor meter resembles a single-phase wattmeter. It differs from the wattmeter in that it has no control spring and has two armature coils. These are mounted on the same shaft in such a way that their axes are about 90 degrees apart. One of the moving coils is connected across the line through a noninductive resistor, so its flux reacts with that of the field coils to produce torque that is proportional to the in-phase (or working) component of line current.

6.40 When the line current is in phase with the line voltage, the currents in B and C are in phase and a torque is exerted between them that aligns their axes so that the pointer indicates unity power factor. The average torque between A and C is zero

because these currents are 90° out of phase when the line power factor is unity.

6.41 When the current in coil C lags the line voltage – for example, by 45° the currents in coil A and coil B both will be out of phase with the current in C. The current in A lags the current in C by 45° and the current in B leads the current in C by 45°. The flux around coil C will therefore react with the resultant fluxes around coils A and B, and the pointer will be moved to a position between zero power factor and unity power factor. In most power-factor meters, lagging current causes the pointer to move to the left of the central position (marked "1.0" on the scale), and a leading current causes the pointer to move to the right of the central position.

6.42 Single-phase power-factor meters are normally made for operation on 115 volts only, because the voltage range of the reactor circuit cannot be extended simply by adding series resistance; they can, however, be used at higher voltages by providing a suitable transformer.

Operating Factors

6.43 Because the indications given by a power-factor meter are dependent upon the instantaneous relationships of current and voltage in the various instrument circuits, and because these relationships are governed by the phase sequence of the coil connections, it is important that the phase sequence specified by the manufacturer be maintained when connecting the meter. This precaution must be observed, specifically, when instrument transformers are used in conjunction with a power-factor meter.

6.44 The torque components for the moving coils depend upon the applied voltage; hence, any appreciable imbalance in phase voltages introduces an error in the instrument indication.

6.45 Single-phase instruments are sensitive to variations in frequency. Consequently, single-phase power-factor meters are rated for operation only at the calibrating frequency. They do not have the relatively wide frequency range of other instruments.

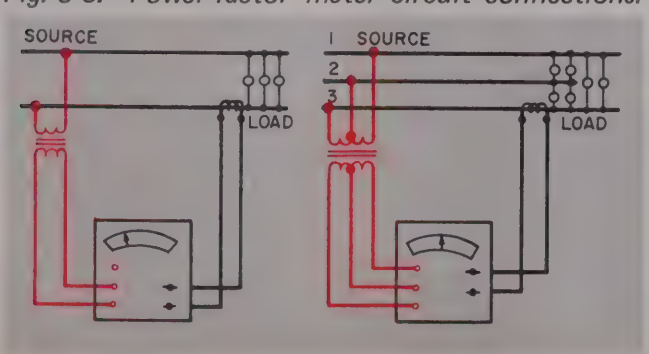
6.46 The current coil in a polyphase power-factor meter is energized from only one phase, and the indication of the instrument is based on the assumption that the load is balanced and the power factor is the same for all phases.

6.47 The potential coils are generally wound for 115-volt operation, with suitable series resistors. They can be furnished, in single or three-phase design, for use up to 575 volts. At higher voltages, potential transformers must be used, as with other A-C instruments.

6.48 When power factor meters are not energized, the pointer has no definite zero position as other instruments, whose restraining torque is a spring, and power-factor meters are called free-balance instruments.

6.49 Power-factor meters will read on scale when the flow of power is from the "Source" to "Load," and, if the load's power-factor is within the scale range; five-ampere meters should be used at or above two amperes. Polyphase power-factor meters are intended for use in balanced circuits only. Power factor measurements are meaningless in unbalanced circuits. Connection diagrams for single and three-phase power factor meters are illustrated in Fig. 6-8.

Fig. 6-8. Power-factor meter circuit connections.



Industrial Analyzer

6.50 The industrial analyzer is, in reality, a miniature switchboard mounted in a portable carrying case complete with instruments, transformers, and switches. It contains the measuring instruments necessary for alternating-current testing and checking of motors and other electrical equipment during installation in industrial plants as well as routine maintenance. The analyzer includes

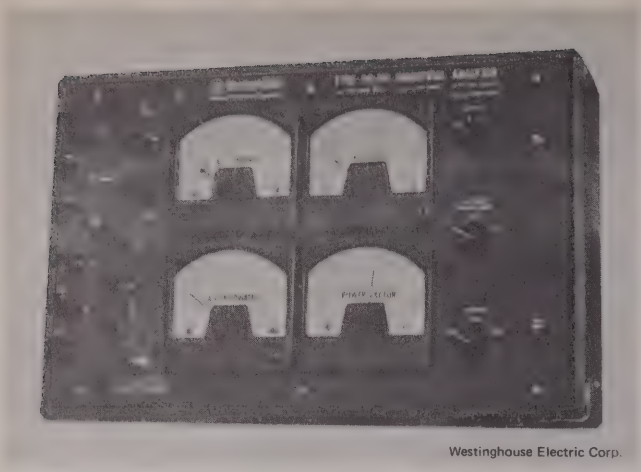


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Fig. 6-9. Industrial circuit analyzer.

an ammeter, voltmeter, wattmeter, and power-factor meter. Figure 6-9 illustrates an industrial analyzer.

6.51 The analyzer is specifically designed to test only alternating current circuits. It may be used on single-phase, two-phase and three-phase circuits. It has current ranges of 5, 25, and 125 amperes, for 120, 240, and 600 volt circuits. Three-phase, four-wire watt measurements are obtained with the use of delta-connected current transformers. Current and voltage ranges beyond the self-contained ranges mentioned can be tested by using external instrument transformers.

6.52 The ammeter is usually equipped with a follow-up pointer for measuring motor-starting currents. A three-position switch is provided to permit the ammeter to measure the current in any one branch of a three-phase line. Another switch connects the voltmeter across any two lines. This switching may be performed under load, which feature provides a quick method for checking load balance and voltage balance on three-phase circuits.

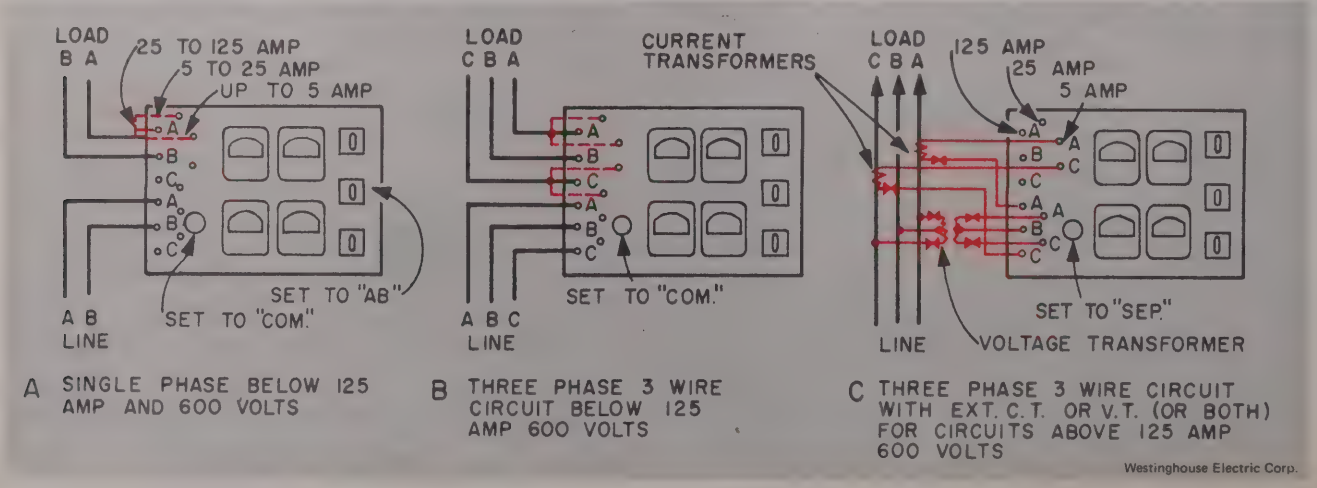
6.53 The various current ranges available are taken care of by taps on the current transformers. Because these taps are brought out to external terminals, it is necessary to change only two leads on the load side to change the range for three-phase circuit measurements.

6.54 The analyzer is connected internally and the terminals are marked for phase sequence A B C. If the phase sequence is not known, make a trial connection with phase notation assumed (ABC). An incorrect connection will be indicated by the pointer of the power-factor meter swinging against one of the stops. The correct connection can then be made by reversing two of the line leads. The corresponding load leads should also be reversed to prevent reversal of rotation of polyphase motors. When using separate voltage terminals with external transformers, make voltage connections properly and switch them when the current leads are reversed.

6.55 The power-factor meter is a polyphase type, which indicates correctly only on balanced three-phase, three-wire circuits. For single-phase and two-phase circuits, the power factor may be readily calculated by dividing the wattmeter reading by the product of the ammeter and voltmeter.

6.56 Without external transformers, the analyzer is rated up to 125 ampere measurements, and is

Fig. 6-10. Methods of connecting industrial analyzer to a circuit.



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completely self-contained. Methods of connecting an industrial analyzer to a circuit to be tested are illustrated in Fig. 6-10. Complete operating instructions are usually placed on the inside cover of an anlyzer.

Current Measurements

6.57 In Fig. 6-10(C), current transformers are connected in the A and C phases so that current entering line terminals A and C leaves at load terminals A and C, respectively. Current taps are provided on the transformer primaries and connected to separate terminals.

6.58 A switch is provided, and it connects the ammeter to the secondary of the current transformers in line A or C to indicate current in line A or C, respectively. To indicate the current in line B, the switch connects the secondaries of the transformers to the ammeter in such a manner as to read the "reversed vector sum of current A and C," which is equal to the current in line B. The current circuit of the analyzer has ample overload capacity to withstand normal starting current surges.

Measuring Starting Current

6.59 To measure the starting current of motors the ammeter pointer is provided with an adjustable "backup" hand. Since the duration of this surge current is only a fraction of a second, the inertia of the moving element of conventional ammeters prevents the pointer from reaching the true peak value of the starting current. By mechanically setting the pointer to a position near the peak value of current, the necessary moving element travel is comparatively small, and it reaches the true position in the short starting-current time.

6.60 Where to set the pointer is determined by first taking a trial reading of the starting current and noting the approximate value. Then set the pointer's backup hand to hold the pointer slightly below the approximate value and start the motor again. The pointer travel is short and peak indication can then be noted with accuracy. Two or three trial settings of the backup hand are usually sufficient to make a setting at which the pointer barely leaves the backup hand. The pointer-reading thus obtained is the true peak value of starting current.

Voltage Measurements

6.61 The analyzer is self-contained to 600 volts, with taps provided in the resistors of the instrument for ranges of 150 and 300 volts. When used on circuits below 600 volts, the voltage terminal switch is set to the position marked COM, which connects the voltage terminals to the regular line terminals, and makes separate external voltage leads unnecessary. For voltages above 600 volts, external voltage transformers must be used.

6.62 Since such transformers usually have 120 volts normal secondary rating, the voltage range changing switch should be set at the 150 volt point and voltage leads connected to the terminals (as shown in the connection diagrams), and the voltage terminal switch should be set to the position marked SEP. For single-phase testing, it is unnecessary to use the separate voltage terminals when external transformers are used. A separate switch is connected in the voltmeter circuit to switch the voltmeter across any two lines of the circuit, making it possible to check voltage-balance conditions.

6.63 A-C motor circuits usually can be checked by removing the fuses in the supply line and connecting the necessary leads from the lines to the analyzer terminals. It is necessary to have protection in the circuit such as circuit breakers or other fuses. Then, in case of trouble, the removal of the fuses for inserting the analyzer will not create a hazard.

6.64 The ammeter, voltmeter and wattmeter read directly on single-phase power, the same as on three-phase power.

6.65 For the maintenance electrician, the industrial analyzer can be a very valuable instrument in solving electrical problems in any industrial plant.

6-9. Many industrial plants install capacitors to compensate for _____ _____.	6-9. REACTIVE POWER VARS REF: 6.23, 6.24
6-10. The varmeter indicates the product of voltage and the out-of-phase current component by use of an _____ element or movement.	6-10. ELECTRODYNAMOMETER REF: 6.25
6-11. A demand meter can serve as a means for indicating a high _____.	6-11. LOAD FACTOR REF: 6.30
6-12. A power factor meter will indicate whether the current is _____ or _____ the voltage.	6-12. LEADING or LAGGING REF: 6.34
6-13. A-C power has two components which are _____ power expended in the load and _____ power serving no useful purpose.	6-13. 1. USEFUL POWER or TRUE POWER 2. REACTIVE POWER REF: 6.35
6-14. Power factor meters can, as most other A-C meters, be used on higher than rated voltages if a suitable _____ is used.	6-14. TRANSFORMER REF: 6.42
6-15. An industrial analyzer is actually a small _____ in a portable case and contains the following meters; _____, _____, _____, and _____-_____ meter.	6-15. SWITCHBOARD, VOLTMETER, AMMETER, WATTMETER, and POWER-FACTOR meter. REF: 6.50
6-16. When using an industrial analyzer, the load and voltage balance conditions of a 3-phase circuit can be determined under load by means of the selector _____.	6-16. SWITCHES REF: 6.52

SELF-CHECK QUIZ

6-1. A wattmeter measures what electrical values?

a. Potential
b. Energy
c. Power
d. All of the above

6-2. When connecting a wattmeter in a circuit, how should the coils be connected?

a. Current in parallel/potential in series
b. Current in series/potential in parallel
c. Current in parallel/potential in parallel
d. Current in series/potential in series

6-3. If a wattmeter is used in a circuit where its safe voltage or current rating is exceeded, the meter will

a. not be affected
b. operate erratically
c. immediately peg the pointer
d. not indicate the overload

6-4. What does the reading of the first dial on the right of a 4-dial watthourmeter indicate?

a. Number of single units
b. Total watts each hour
c. Maximum value the meter can register
d. Multiplier value of the preceding dial

6-5. A varmeter is used to indicate the

a. internal A-C overloads
b. out-of-phase voltage change
c. amount of reactive power
d. amount of true power

6-6. A demand meter is a means of indicating which of the following?

a. Peak power periods
b. A high load factor
c. Low KWH consumption
d. All of the above

6-7. Which of the following demand meter readings are normal terms?

a. Kilovars
b. Kilowatts
c. Kilovolt-amperes
d. All of the above

6-8. Which of the following does a power factor meter indicate?

a. Continuous power
b. Power difference between phases
c. The current is leading or lagging the voltage
d. Reactive and useful power

6-9. An industrial analyzer is NOT suitable for measuring which of the following?

a. Power
b. Resistance
c. Current
d. Power factor

6-10. Without external voltage transformers, the industrial analyzer can be used on circuits up to

a. 600 volts
b. 480 volts
c. 240 volts
d. 120 volts

ANSWERS TO SELF-CHECK QUIZ

6-1. c. Power. REF: 6.01.

6-2. b. Current in series/potential in parallel. REF: 6.02.

6-3. d. Not indicate the overload. REF: 6.04.

6-4. a. Number of single units. REF: 6.18.

6-5. c. The amount of reactive power. REF: 6.23.

6-6. d. All the above. REF: 6.30.

6-7. d. All the above. REF: 6.33.

6-8. c. The current is leading or lagging the voltage. REF: 6.34.

6-9. b. Resistance. REF: 6.50.

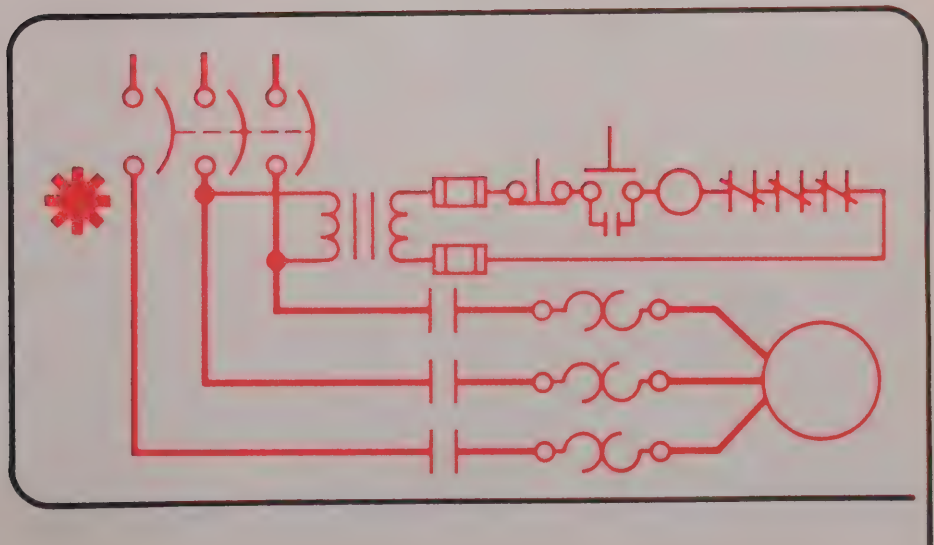
6-10. a. 600 volts. REF: 6.61.

LESSON SEVEN

SPECIAL INSTRUMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Seven — Special Instruments

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Lesson Seven — Special Instruments

Preface

When you are sent to troubleshoot a fault, you do not know what you will encounter until you are at the job site. Will you need to measure A-C or D-C voltages or resistance values to help locate the fault? Is there a general purpose or special instrument for this situation?

Occasions may arise when you need to know the EXACT resistance of a component. The ohmmeter does not provide precision measurement. What instrument should be used for precise measurement of resistance?

When the values or characteristics of a capacitor or an inductance coil in a piece of equipment are questionable, what test equipment can be used to determine the value of these components?

This lesson answers the above questions by introducing: (1) the general purpose multimeter to measure A-C or D-C voltages and resistance, and (2) special circuits for precise measurement of resistance, and (3) A-C circuits that will measure capacitance and inductance.

The Multimeter

7.01 The MULTIMETER is a multipurpose instrument that can measure resistance, voltage, and current. It has a one-milliamp meter. The face of the instrument has separate graduated scales to indicate the three values that can be measured. The multimeter is also known as the volt-ohm-milliammeter (VOM).

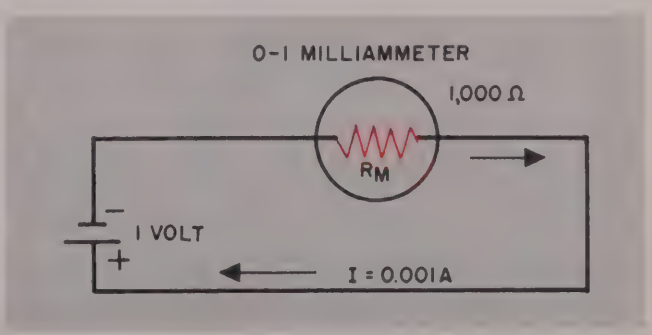
7.02 The VOM uses the basic D'Arsonval meter movement. Each basic meter movement has a maximum current rating. The current range of a basic meter is extended by a simple device called a shunt.

Current Measurement

7.03 A meter has a certain amount of resistance. The common 1-milliamp meter has a resistance of 1000 ohms. A simple circuit with a meter resistance represented by R_M is illustrated in Fig. 7-1. One milliampere (0.001 amp) is required for full-scale reading. One volt is required to produce the current through 1000 ohms. (Applying Ohm's Law, E = I x R, E = 0.001 x 1000 = 1 volt.)

7.04 To allow a 1-milliamp meter to measure current in a circuit larger than 0.001 amps, a shunt resistor is placed in parallel with the meter.

Fig. 7-1. A basic meter circuit.



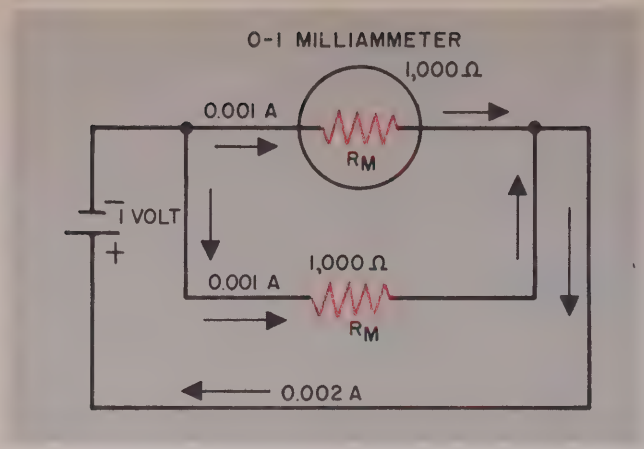


Fig. 7-2. Shunt resistor across meter increases meter range.

7.05 A 1000 ohm shunt resistor is connected in parallel with the meter, as illustrated in Fig. 7-2. If one milliamp of current flows through the meter, then one milliamp of current flows through the shunt resistor. The meter pointer indicates a full-scale reading, the actual current flow from the source is two milliamperes. The meter range was increased to two milliamperes.

7.06 By selecting various shunts, the meter can be made to indicate a range of currents. The usual ranges are: 1 milliamp, 10 milliamps, 100 milliamps, and 1 amp.

7.07 A simple circuit drawing for a multirange ammeter is shown in Fig. 7-3. The values of the shunt resistors can be found by the following formula:

$$R_S = \frac{I_M \times R_M}{I_S}$$

R_S = shunt resistance in ohms.

I_M = current rating of meter in amperes.

R_M = meter movement resistance in ohms.

I_S = current flow through the shunt in amperes.

This formula can be used to find the value of shunt resistance required for any meter and range desired.

7.08 The current flow through the shunt (I_S) is found by subtracting the meter current (I_M) from the desired range. The remainder of the current is the shunt current (I_S).

7.09 As an example, a 1-milliamp meter whose resistance is 1000 ohms is to be used to measure 1 amp. What is the resistance of the shunt required to increase the meter range to one ampere?

$$I_S = 1.00A - I_M$$

$$= 1.000A - 0.001A$$

$$= 0.999A$$

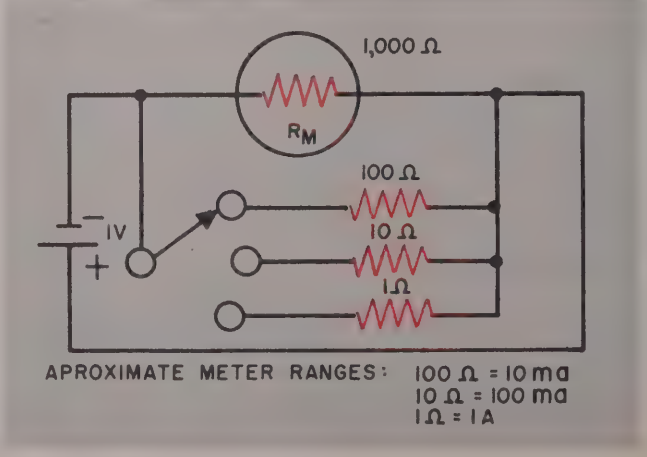
$$R_S = \frac{I_M \times R_M}{I_S} = \frac{0.001 \times 1000}{0.999} = 1.001 \text{ ohms}$$

7.10 A shunt of 1.001 ohms is required to extend the meter range to one amp. When the meter resistance and full-scale current are known, any value of shunt resistance can be found using the equation. The smallest current that can be measured is limited by the meter movement itself. The value of the shunt resistance will not be greater than the resistance of the meter. The shunt resistance is either equal to or less than the meter resistance.

Voltage Measurement

7.11 One volt is required for a current of 1 milliamp to flow through 1000 ohms, as illustrated in Fig. 7-1. The meter actually indicates the amount of voltage present across the battery because E = I x R. This is how an ammeter is used to indicate voltage. When an ammeter is used to measure voltage, the meter scale is calibrated in volts.

Fig. 7-3. Shunt resistance for three meter ranges.



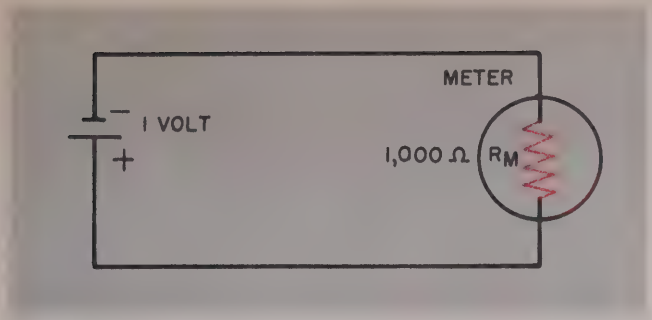


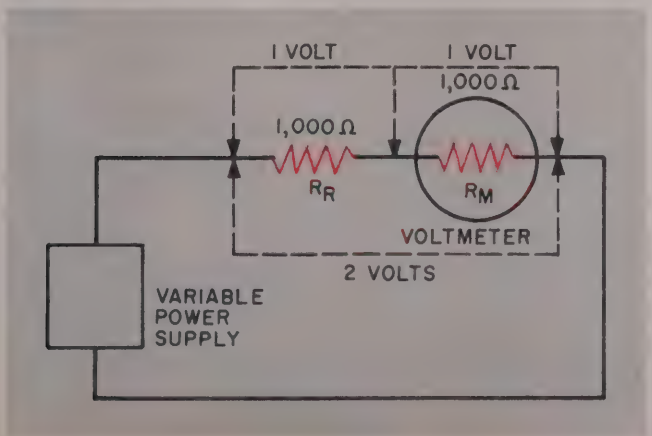
Fig. 7-4. A simple voltmeter circuit.

7.12 When using a 1-milliamp-meter movement with a resistance of 1000 ohms, the maximum voltage which can be measured is 1 volt (E = I x R). The voltage range as well as the current range can be extended. When measuring voltage, a different circuit than the one used for extending the current range is used. Resistors are used in parallel to extend the current range of the meter. To extend the voltage range, resistors or MULTIPLIERS are used in series with the meter.

7.13 The circuit in Fig. 7-4 shows a meter and a battery. The battery voltage is 1 volt. Because the meter is in parallel with, or across the battery, there is 1 volt across the meter. The voltage across the meter must never exceed 1 volt, since the total current through the meter cannot exceed 1 milliampere for full-scale deflection.

7.14 Kirchhoff's Law states, "The sum of the voltage drops around a series circuit is equal to the applied voltage." A 1000 ohm resistor connected in series with the meter circuit is illustrated in Fig. 7-5. The total resistance of the circuit is 2000 ohms. (1000 ohms meter resistance plus 1000 ohms multiplier resistance.) When the voltage,

Fig. 7-5. Extending voltmeter range with multiplier resistor R_R.



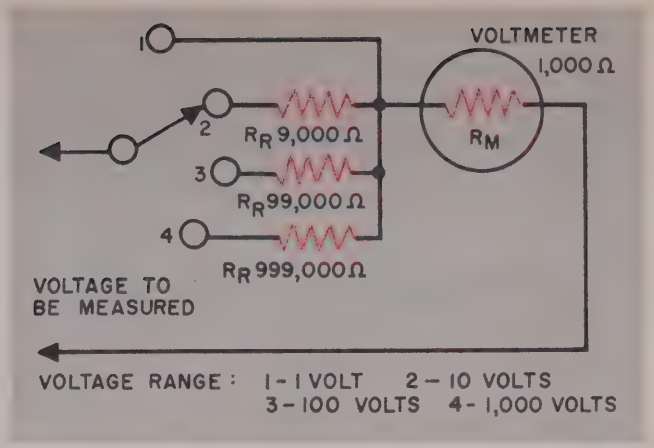


Fig. 7-6. Switched multipliers (R_R) for three different voltage ranges.

from the variable power supply, is gradually increased from zero volts until the meter pointer indicates full-scale, there is 1 volt across the meter and 1 volt across the multiplier. The power supply voltage is 2 volts.

7.15 The circuit resistance is 2000 ohms. The maximum current for full-scale deflection through the meter is 0.001 amps. The current in any series circuit is the same through all parts. Therefore the current through the 1000 ohm multiplier resistor is also 0.001 amps. Using Ohm's Law E = I x R = 0.001 x 2000 = 2 volts.

7.16 The common voltage ranges are 1, 10, 100, and 1000 volts. To find the value of resistance of the multiplier resistor R_R, Ohm's Law is used.

$$R_R + R_M = \frac{\text{E (voltage range)}}{\text{I (meter current)}}$$

R_R = multiplier resistance

R_M = meter movement resistance

7.17 To extend a voltmeter range to measure 1000 volts using the basic 1-milliamp meter, for example, use the following formula:

$$R_T = \frac{E}{I} = \frac{1000}{0.001} = 1{,}000{,}000 \text{ ohms}$$

One million ohms is the total resistance ($R_T = R_R + R_M$) required in the circuit. The meter resistance is 1000 ohms. The multiplier resistance $R_R = R_T - R_M$, 1,000,000 − 1,000 = 999,000 ohms. Multiplier resistors are switched for the different ranges, as illustrated in Fig. 7-6.

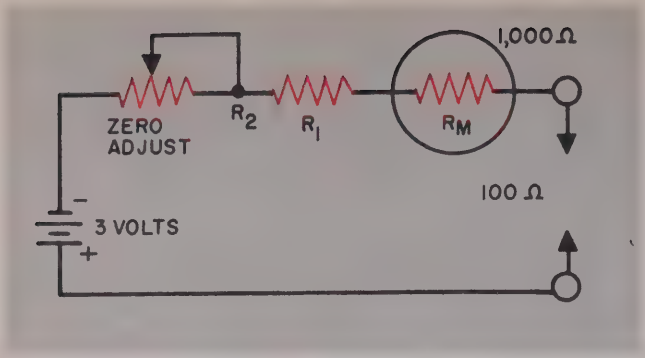


Fig. 7-7. Basic ohmmeter circuit.

Resistance Measurement

7.18 The same basic meter used to measure current and voltage is used to measure resistance. The circuit illustrated in Fig. 7-7 is a basic ohmmeter circuit. When measuring current and voltage, the power required to operate the meter is supplied by the circuit being measured. To measure resistance, a source of power must be furnished. This power is supplied by a battery contained in the housing of the multimeter.

7.19 In Fig. 7-7, resistor R_1 limits the current flow in the circuit. The variable resistor R_2 also limits the current flow in the circuit, but it varies the amount of current, and its basic function is to compensate for battery aging. R_2 is also the ohm's scale zero adjustment.

7.20 One milliamp of current is required for full-scale deflection of the meter. Before resistance measurements can be made, the meter must be zeroed. This is accomplished by touching or shorting the test probes together. The zero ohms-adjust control, R_2, is adjusted until the meter pointer is exactly on 0 (zero) of the ohms scale. The current in the series circuit is then 1 milliamp. When the test probes are placed across a 100 ohm resistor, the meter pointer will indicate less than 1 milliamp.

7.21 Before measuring the 100 ohm resistor, the ohmmeter circuit of Fig. 7-7 was adjusted so that 1 milliamp of current flowed through the circuit. Since the ohmmeter circuit is a series circuit, the total resistance (R_T) of the circuit is the sum of $R_M + R_1 + R_2$. Using Ohm's Law

$$R_T = \frac{E}{I} = \frac{3}{0.001} = 3000 \text{ ohms}$$

The value of $R_1 + R_2 = R_T - R_M = 3000 - 1000 = 2000$ ohms.

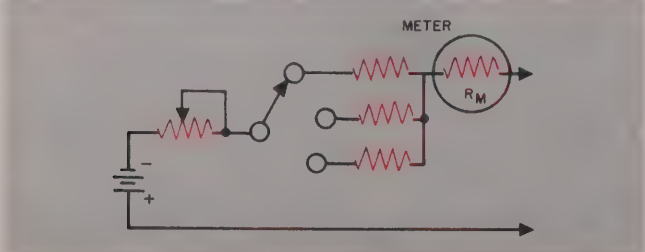
7.22 When the test probes are placed across the 100 ohm resistor, the resistor is in series with the circuit and the total circuit resistance becomes 3000 ohms + 100 ohms = 3100 ohms. The current in the circuit will be less (according to Ohm's Law).

$$I = \frac{E}{R_T}$$

$$I = \frac{3}{3100} = 0.00096 \text{ amps}$$

This current causes the meter movement to indicate the amount on the instrument scale, which is calibrated to read in ohms. The resistance in this

Fig. 7-8. Multirange ohmmeter circuit.



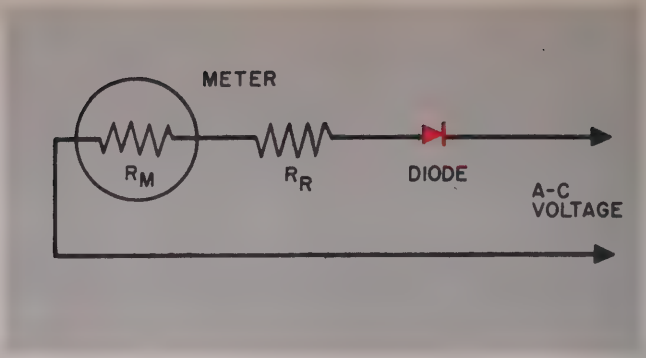


Fig. 7-9. A single diode circuit for A-C measurements.

Fig. 7-10. A bridge rectifier for A-C measurements.

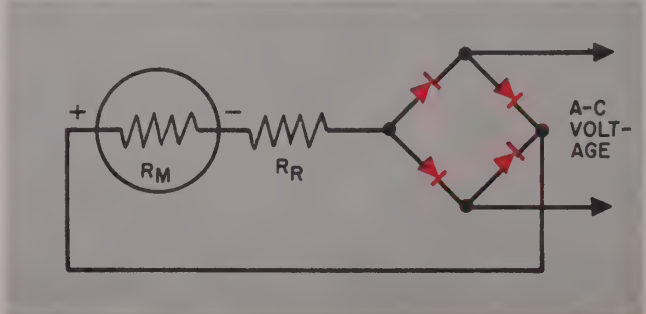


Fig. 7-11. Multimeter.

example is read on the ohms scale, and it should indicate 100 ohms.

7.23 A typical multirange ohmmeter circuit is shown in Fig. 7-8. Several ranges allow the meter to measure from 0 to about 1 megohm.

A-C Voltage Measurement

7.24 To enable the D-C meter of the VOM to measure A-C voltages, additional components are needed. One method, illustrated in Fig. 7-9, is the use of a diode to change the A-C to D-C. This circuit rectifies only one-half of an A-C cycle. Another circuit, illustrated in Fig. 7-10, uses four diodes in a full-wave bridge rectifer. This circuit rectifies the full A-C cycle.

7.25 The multiplier resistors, R_R are the same as the resistors in the D-C voltage circuit for extending the meter range.

7.26 Figure 7-11 is a photograph of a multimeter commonly used in electrical maintenance.

7.27 At the lower left-hand corner of the meter panel are two jack connections. One jack connection is marked COMMON, the black test lead should be plugged into this jack. The other jack connection is marked +, the red test lead should be plugged into this jack.

7.28 Above the test lead jack connection is a selector switch knob for selecting –D-C, + D-C or A-C. This knob is turned to the proper position for the type of circuit to be measured.

7.29 In the center of the panel is the RANGE switch. This is a twelve-position switch used to select one of three resistance ranges, or one of six current ranges. The 10-amp current range is brought out to separate jack connectors marked – 10A and + 10A, because of the magnitude of the current. The 50 μamps (microamps) is a separate jack because of the special circuit required when measuring small current.

7.30 There are five positions for voltage selection plus special jacks for 5000 V A-C and 5000 V D-C.

7.31 These operational procedures should be followed when making measurements with the meter.

A-C VOLTS MEASUREMENT – Turn selector switch to A-C. Turn range switch to 1000 V position. Now measure the A-C circuit and if meter pointer is not sufficiently deflected, turn range switch to next lower range until deflection is sufficient for a proper reading.

OHMS MEASUREMENT – Turn selector switch to + D-C. Turn range switch to R x 1 or R x 100 or R x 10,000, depending on the resistance range desired. Short the two test leads together and set the meter pointer to zero ohms (top scale and zero on right side of scale) by rotating ZERO OHMS knob. The resistance can now be measured.

D-C CURRENT MEASUREMENT – Turn selector switch to + D-C. Black test lead in – jack and red test lead in + jack for ranges from 10 ma to 500 ma. Use jacks marked – 10A and + 10A for current reading above 500 ma.

D-C VOLTS MEASUREMENT – Turn selector switch to + D-C. Turn range switch to 1000 V range and then take the voltage measurement. If the pointer does not indicate, then move the range switch to the next lower range until desired range is obtained.

Use these programed exercises to help check your learning progress.

7-1. A multimeter is capable of measuring three electrical quantities. Name them. _____ _____ _____	7-1. CURRENT, VOLTAGE, RESISTANCE REF: 7.01
7-2. Another name for the multimeter is _____-_____-_____.	7-2. VOLT-OHM-MILLIAMMETER (VOM) REF: 7.01
7-3. The multimeter has several *current* ranges. This is accomplished by the use of different _____.	7-3. SHUNTS REF: 7.06
7-4. A 1-milliamp meter whose resistance is 1000 ohms is to be used to measure 5 amps. Calculate the required resistance of the shunt. _____	7-4. $I_S = 5.000A - 0.001A = 4.999A$ $R_S = \frac{I_M \times R_M}{I_S} = \frac{0.001 \times 1000}{4.999} = 0.200$ ohms REF: 7.09
7-5. The multimeter has several *voltage* ranges. This is accomplished by the use of different _____.	7-5. MULTIPLIERS REF: 7.12
7-6. When a 1-milliamp, 1000-ohm meter reads 500 volts, what is the value of the multiplier? _____	7-6. $R_T = \frac{500}{0.001} = 500{,}000$ ohms $R_R = R_T - R_M$ $= 500{,}000 - 1000 = 499{,}000$ ohms REF: 7.17
7-7. When preparing the multimeter for measuring resistance, what control should you adjust so the meter pointer is exactly on 0 (zero) of the ohms scale?	7-7 ZERO-OHMS ADJUST CONTROL REF: 7.20
7-8. A multirange ohmmeter circuit allows the meter to measure resistance from zero to _____ _____.	7-8. ONE MEGOHM REF: 7.23

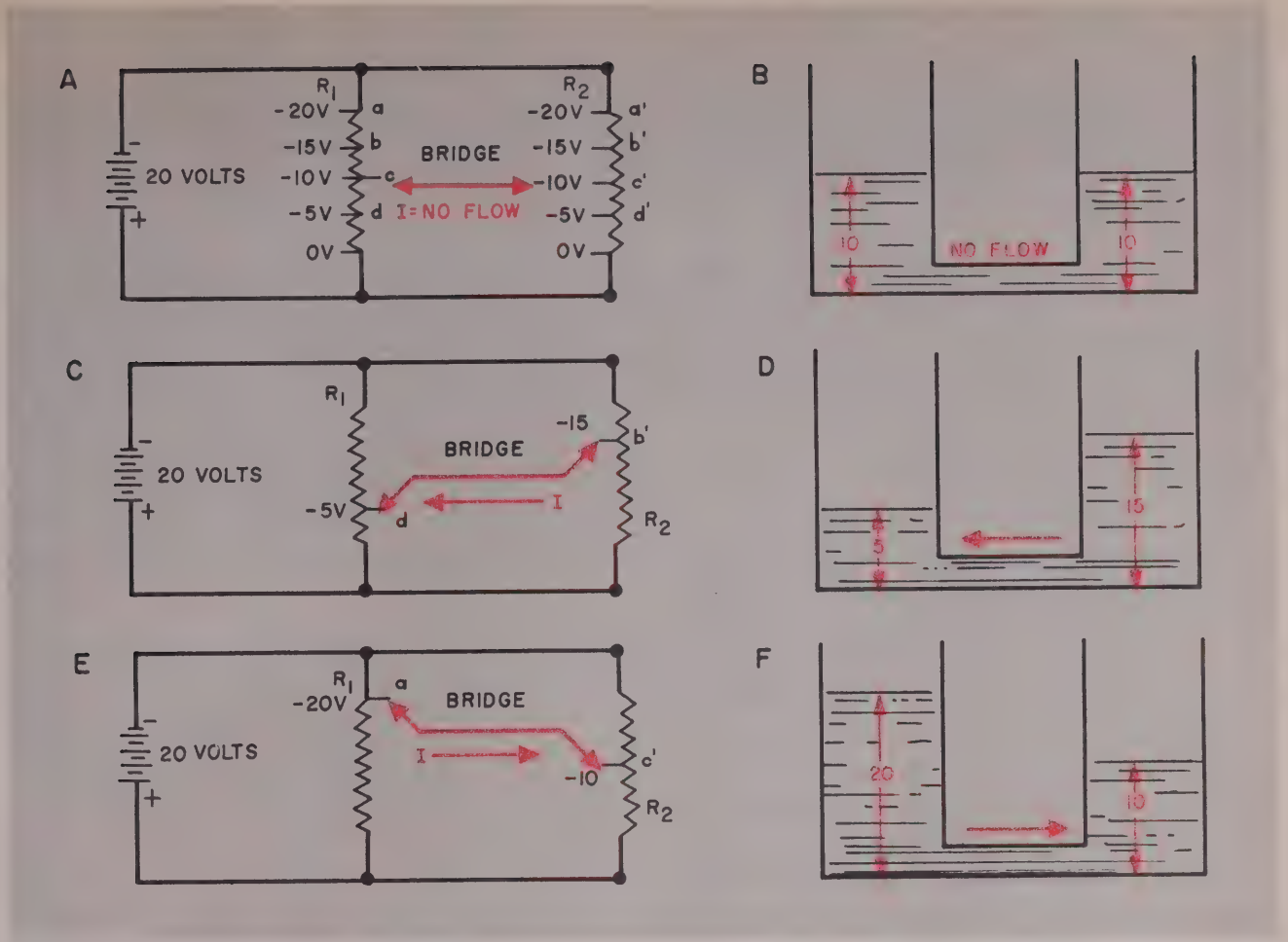


Fig. 7-12. Simple resistance bridges.

Bridge Circuits

7.32 A resistance bridge circuit in its simplest form is illustrated in Fig. 7-12. Two identical resistors, R_1 and R_2, are connected in parallel across a 20-volt power source. The network becomes a bridge circuit when a cross connection or "bridge" is placed between the two resistors.

7.33 The voltage across both resistors is dropped at the same rate, because the resistors are identical. Therefore, points a - a′, b - b′, c - c′, and d - d′ are at equal potentials. If the bridge is connected between points of equal potential, as in Fig. 7-12(A), no current will flow through the bridge.

7.34 It is analogous to water. Figure 7-12(B) illustrates two 20-gallon tanks, each with 10 gallons of water. Since both tanks have equal amounts of water (at the same level), no water will flow between the two tanks.

7.35 If the bridge is connected between two points of unequal voltage, current will flow from the negative end to the more positive end, as shown in Fig. 7-12(C), or the current flows from right to left (b′ to d).

7.36 If the two 20-gallon tanks have unequal amounts of water as in Fig. 7-12(D), water will flow from the tank with 15 gallons of water to the tank with only 5 gallons of water, or from the right tank to the left tank.

7.37 In Fig. 7-12(E) current flows from left to right, or a to c′. Thus, it can be seen that the direction of the bridge current is controlled by the relative potential at the two ends of the bridge resistor.

7.38 In Fig. 7-12(F), the tank on the left has 20 gallons of water and the tank on the right has 10 gallons of water. The water will flow from left to right. As with electric current, the water flow is controlled by the level of the water in the tanks.

7.39 When the bridge is across equal potentials, and no current flows, it is said to be BALANCED. When the bridge is across unequal potentials, and current tends to flow, it is said to be UNBALANCED. The same analogy is true for the water tanks.

7.40 A resistance bridge may be unbalanced in either or both of the following ways: (1) by connecting the bridge to unequal potentials, or (2) by using resistors of unequal values, thus causing an unbalance.

Wheatstone Bridge

7.41 A type of circuit that is widely used for precision measurements of resistance is called a WHEATSTONE bridge. The circuit diagram of a Wheatstone bridge is shown in Fig. 7-13. R_1, R_2, and R_3 are precision variable resistors, and R_X is the resistor whose unknown value of resistance is to be determined. After the bridge has been properly balanced, the unknown resistance can be determined, using a simple formula. The galvanometer G, which is an integral part of the instrument, is inserted across terminals b and d to indicate the condition of balance. When the bridge is properly balanced, there is no difference in potential across terminals b and d. When the switch is closed, the galvanometer deflection is zero.

7.42 The operation of a Wheatstone bridge is explained as follows. In Fig. 7-13, when the switch to the battery is closed, electrons flow from the negative terminal of the battery to point a. Here the current divides, as it does in any parallel circuit, and part of it passes through R1 and R2 and the remainder passes through R3 and R_X. The two currents labeled I_1 and I_2 unite at point c and return to the positive terminal of the battery. The value of I_1 depends on the sum of resistances R_1 and R_2, and the value of I_2 depends on the sum of resistances R_3 and R_X. In each case, according to Ohm's Law, the current is inversely proportional to the resistance.

7.43 R_1, R_2, and R_3 are adjusted so that when the galvanometer switch is closed there will be no deflection of the needle. When the galvanometer shows no deflection, there is no difference in potential between points b and d. This means that

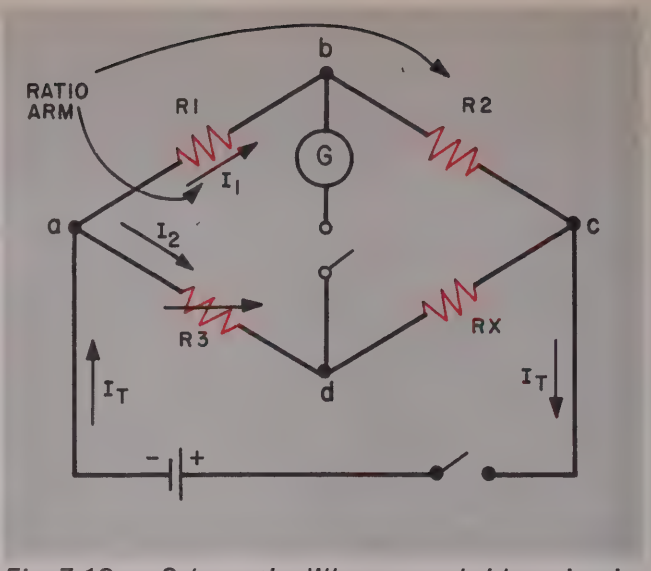


Fig. 7-13. Schematic Wheatstone-bridge circuit.

the voltage drop (E_1) across R_1, between points a and b, is the same as the voltage drop (E_3) across R_3, between points a and d. By similar reasoning, the voltage drops across R_2 and R_X, that is, E_2 and E_X, are also equal. Expressed algebraically, $E_1 = E_3$, or $I_1 R_1 = I_2 R_3$, and $E_2 = E_X$, or $I_1 R_2 = I_2 R_X$,

7.44 Dividing the voltage drops across R_1 and R_3 by the respective voltage drops across R_2 and R_X,

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_X}$$

Simplifying,

$$\frac{R_1}{R_2} = \frac{R_3}{R_X}$$

Therefore,

$$R_X = \frac{R_2}{R_1} R_3$$

The resistance values of R_1, R_2, and R_3 are readily determined from the markings on the standard resistors, or from the calibrated dials if a dial-type bridge is used.

7.45 For example, the Wheatstone bridge represented in Fig. 7-13 is used to determine the value of the unknown resistance R_X. When the bridge is

balanced, R_3 is 152 ohms, R_1 is 10 ohms, and R_2 is 100 ohms. What is the value of R_X?

$$R_X = \frac{R_2}{R_1} R_3$$

$$= \frac{100}{10} \times 152 = 1520 \text{ ohms}$$

Resistances R_1 and R_2 are called the ratio arms of the bridge. The ratio arms are usually made to equal a definite ratio such as 1 to 1, 10 to 1, or 100 to 1. Resistance R_3 is called the variable arm and is made continuously variable from 1 to 1,000 or from 1 to 10,000 ohms. When the bridge is balanced, the value of the unknown resistance is equal to the value of R_3 multiplied by the ratio of R_2 to R_1.

7.46 On industrial dial-type bridges as shown in Fig. 7-14, the ratio of R_2 to R_1 is selected by means of a rotary switch, the selected ratio is indicated on the dial. (The ratio dial is in the upper left corner of the picture.) The variable arm R_3 is adjusted by four rotary switches. (R_1, R_2, and R_3 correspond to the resistance in Fig. 7-13.) One switch varies the resistance in steps of 1 ohm, another in steps of 10 ohms, the third in steps of 100 ohms, and the fourth in steps of 1000 ohms. If you will look closely at the picture of the Wheatstone bridge in Fig. 7-14, you will note that the ratio dial is set on .1. The 1000 dial is set on 2. The 100, 10, and 1 dials are all set on 0. The reading is 2000 x .1 = 200.0 ohms. The manufacturer attached operating instructions to the inside of the cover, as well as a schematic of the internal circuit.

Fig. 7-14. Wheatstone bridge.

Capacitance Bridge

7.47 The Wheatstone bridge is one of the most convenient and accurate methods of measuring resistance. Similarly, one of the most accurate methods of measuring impedances is by the use of an A-C impedance bridge, a modification of the Wheatstone bridge (see Fig. 7-15). An A-C source replaces the battery, and earphones are used instead of a meter.

7.48 Until the bridge is balanced, an A-C voltage exists across the earphones, and a tone is heard. There is no voltage across the earphones after the bridge is balanced. The equation is as follows:

$$I_1 Z_1 = I_2 Z_3 \text{ and } I_1 Z_2 = I_2 Z_X$$

Solving the two equations and eliminating the current terms, the resulting formula is

$$Z_X = \frac{Z_2}{Z_1} Z_3$$

Note that the equation is the same as

$$R_X = \frac{R_2}{R_1} R_3$$

except that impedance (Z) is substituted for resistance (R).

Inductance Bridge

7.49 Accurate measurements of unknown quantities can be made by comparison with a standard quantity of the same type. An accurate method of measuring impedances is using an A-C impedance-balancing network. This is a modification of the Wheatstone bridge.

7.50 In an inductance bridge, the unknown inductance is compared with one of a known value.

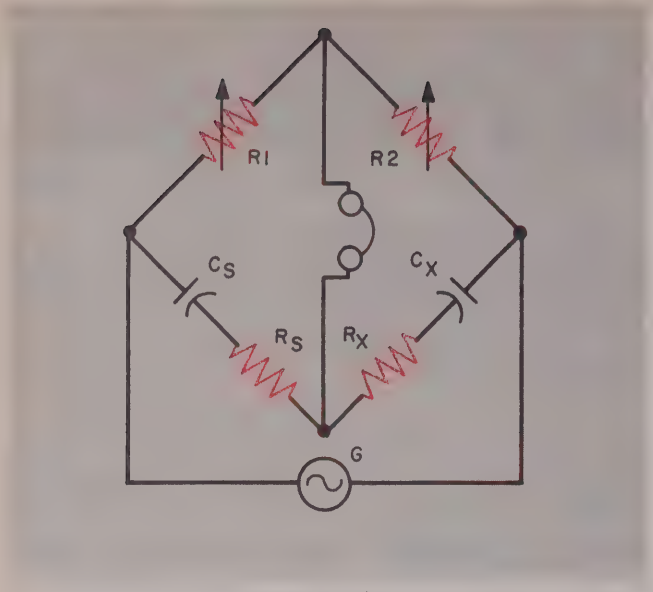


Fig. 7-15. Capacitance bridge.

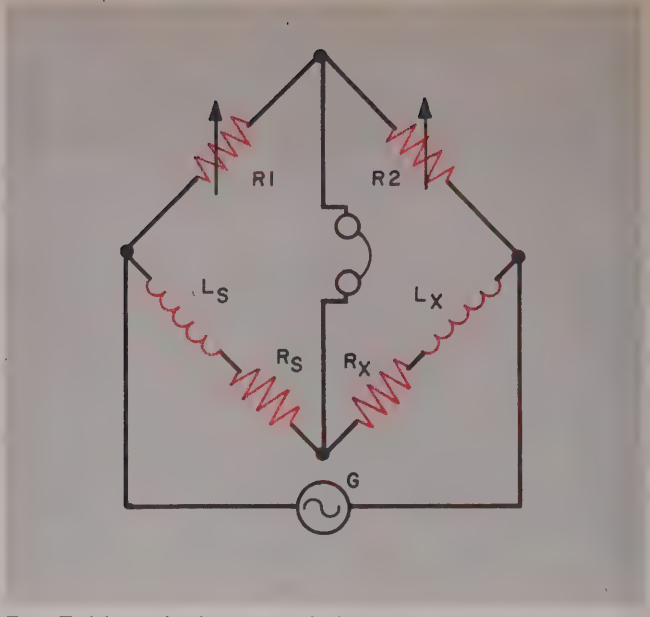


Fig. 7-16. Inductance bridge.

Since inductances also have resistance, the standard arm of the bridge must also contain a known resistance.

7.51 Figure 7-16 illustrates an inductance bridge. The standard resistance, R_S, is in series with the standard inductance, L_S. When the network is balanced so that no tone is heard in the earphones, the following equations apply. One equation is for obtaining the value of the unknown resistance (R_X) of the inductances,

$$R_X = R_S \frac{R_2}{R_1}$$

The second equation is for obtaining the value of the unknown inductance (L_x),

$$L_X = L_S \frac{R_2}{R_1}$$

A frequency source of 1000 Hz is used as an easily-heard tone.

7.52 If the ratio arm Z_2/Z_1 is replaced by a resistance ratio arm R_2/R_1, then the quantities are limited to the unknown impedance Z_X and a standard impedance is used; Z_S is substituted for Z_3.

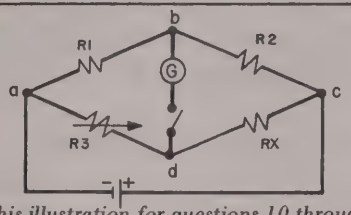
7.53 There are many different forms of A-C bridges. One of the most common is that in which the standard impedance is of the same type as the unknown to be measured. Therefore, in order to measure capacitance, the standard impedance is a standard variable capacitor. If the capacitor to be measured has an appreciable resistive component, the standard arm of the bridge network must also have a standard variable resistance.

7.54 The standard resistance R_S and the standard capacitor C_S in Fig. 7-16 must both be varied to obtain a balance for both components of the unknown impedance, $C_X R_X$. The A-C source applied to the bridge should have an easily-heard frequency. A frequency of 1000 Hz is satisfactory.

7.55 When the capacitance bridge is balanced, this equation applies:

$$C_X = \frac{R_2}{R_1} C_S$$

Note the similarity of this equation to the equation for resistance and impedance.

7-9. A circuit used for very precision measurement of resistance is called a _____ _____.	7-9. WHEATSTONE BRIDGE REF: 7.41
 *(Use this illustration for questions 10 through 14.)*	
7-10. When a Wheatstone bridge is properly balanced, the galvanometer deflection is _____	7-10. ZERO REF: 7.41
7-11. In the circuit shown, when the switch is closed and the galvanometer shows no deflection, there is no difference in potential between points _____ and _____.	7-11. b and d REF: 7.45
7-12. When the circuit shown is balanced, R1 = 10 ohms, R2 = 100 ohms, and R3 = 243 ohms. What is the value of RX? _____	7-12. $RX = \frac{R2}{R1}\ R3 = \frac{100}{10} \times 243 = 2430$ ohms REF: 7.45
7-13. In the circuit shown, resistances R1 and R2 are called the _____ arms of the bridge.	7-13. RATIO ARMS REF: 7.45
7-14. In the circuit shown, R3 is called the _____ arm of the bridge.	7-14. VARIABLE ARM REF: 7.45
7-15. In an inductance or capacitance bridge, what device is used to detect a balanced bridge? _____	7-15. A PAIR OF EARPHONES REF: 7.47

Ohmmeters are part of a volt-ohm-milliammeter (VOM).

A small battery is contained inside a VOM. This battery operates the ohmmeter. A battery becomes weaker after it has been in use for some time. For this reason, a battery-voltage adjustment is provided on a VOM. The battery-voltage adjustment is a small knob. It is called a "zero ohms" control on the VOM.

An ohmmeter must never be connected into an energized circuit. Unless the circuit is deengerized the ohmmeter will be damaged, or will burn out.

When a VOM is switched from one range to another, the "zero ohms" control must be re-adjusted. Otherwise, the scale reading may be incorrect.

The VOM has several D-C voltage ranges. Switch the VOM to its highest D-C voltage range first, when making a D-C voltage measurement. This prevents the possibility of damage to the meter.

VOM test leads must be connected with correct polarity to the circuit under test. Otherwise, the pointer will swing off-scale or against the pointer stop. A VOM is not damaged when the test leads are connected in wrong polarity. However, if this happens, the test leads must be reversed to obtain an on-scale reading. After the test leads are connected to the circuit under test, reduce the setting of the range switch to obtain a reading from ¼ to ¾ of full scale.

Resistance ranges are provided to make it possible to read resistance values over a wide range.

BRIDGE MEASUREMENT is an accurate method of measuring the parameters of circuit components, such as resistance, capacitance, and inductance and also related circuit properties. The starting point for all types of bridge networks is the Wheatstone bridge. This consists of four resistance arms, a galvanometer and a battery or hand-driven generator. Three of the resistances are known, and the fourth resistance is the one to be determined.

Balance is more complex in A-C bridges, because both magnitude and phase angle of impedances enter into the balance condition. However, this fact makes possible the precise measurement of reactive components – capacitors and inductors – as well as of resistors.

Inductance may be measured by means of a simple Wheatstone bridge, and this is usually called an *inductance bridge*.

Capacitance may be measured by means of a Wheatstone bridge, and this is usually called a *capacity bridge*.

SELF-CHECK QUIZ

7-1. What three electrical quantities can be measured by a multimeter?

a. Voltage, current, watts
b. Voltage, current, resistance
c. Voltage, current, amperes
d. Voltage, watts, vars

7-2. A multimeter is often called VOM. What does VOM mean?

a. Volt-ohm-meter
b. Volt-ohm-megameter
c. Volt-ohm-milliammeter
d. Volt-ohm-microammeter

7-3. A multimeter has different shunts, which increase the

a. current range
b. voltage range
c. resistance range
d. impedance range

7-4. A multimeter uses different multipliers to increase the

a. current range
b. voltage range
c. resistance range
d. impedance range

7-5. To measure resistance with a multimeter, the pointer must first be adjusted (with the test leads shorted together) to zero on the ohms scale by the

a. range switch
b. selector switch
c. meter zero screw
d. zero ohms adjustment

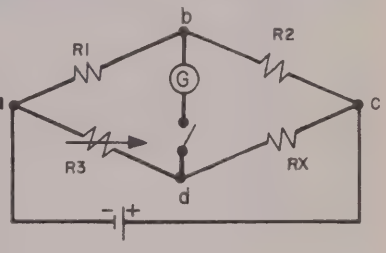
7-6. A Wheatstone bridge is used to electrically measure

a. current
b. resistance
c. voltage
d. power

7-7. When a Wheatstone bridge is balanced, the galvanometer reads

a. zero current
b. maximum current
c. zero voltage
d. maximum voltage

7-8. In the illustration shown the ratio arms of the bridge are



a. $R_1 R_3$
b. $R_1 R_2$
c. $R_3 R_X$
d. $R_2 R_3$

7-9. In the circuit shown in 7-8 above, the variable arm of the bridge is

a. R1
b. R2
c. R3
d. R4

7-10. What type of a bridge circuit is used to measure inductance and capacitance?

a. Wheatstone bridge
b. D-C bridge
c. A-C bridge
d. A-C, D-C bridge

ANSWERS TO SELF-CHECK QUIZ

7-1. b. Voltage, current, resistance. REF: 7.01.

7-2. c. Volt-ohm-milliammeter. REF: 7.01.

7-3. a. Current range. REF: 7.06.

7-4. b. Voltage range. REF: 7.12.

7-5. d. Zero ohms adjustment. REF: 7.20.

7-6. b. Resistance. REF: 7.41.

7-7. a. Zero current. REF: 7.41.

7-8. b. $R_1 R_2$. REF: 7.45.

7-9. c. R3. REF: 7.45.

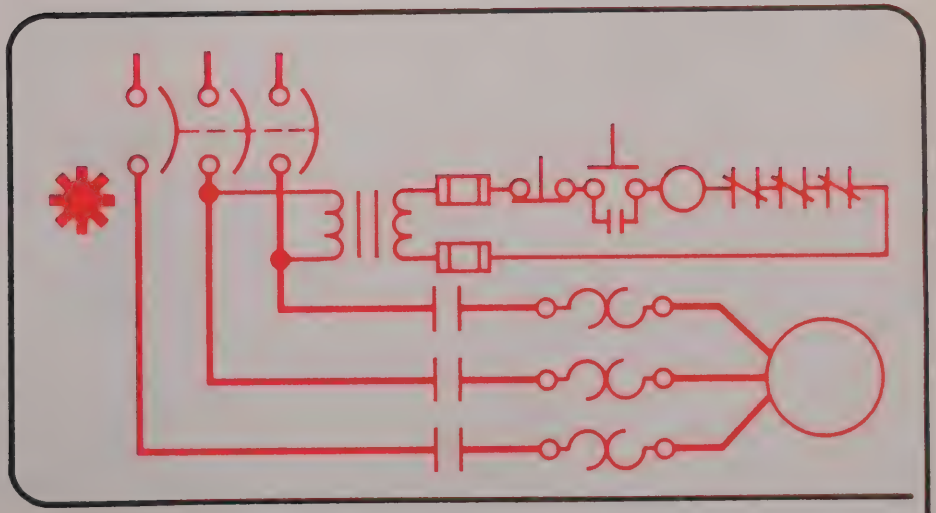
7-10. c. A-C bridge. REF: 7.47.

LESSON EIGHT

INDICATING INSTRUMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Eight — Indicating Instruments

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Lesson Eight — Indicating Instruments

Preface

Electrical repairs require fast service. When production is at a standstill, it is costing the company money. Troubleshooting must be quick and efficient. It is not necessary to carry cumbersome meters to every job. Sometimes it is only necessary to have some indication that power is present.

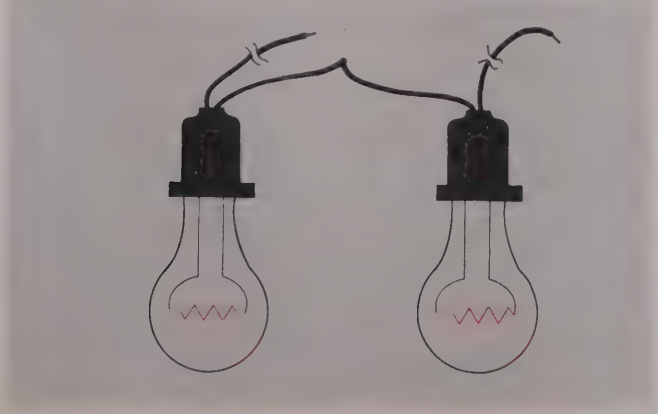
This lesson illustrates and explains the use of simple indicating devices. The devices are instant aids, which help you determine the condition of a circuit quickly and easily. A knowledge of the use of indicating instruments will make a complicated troubleshooting task much easier to perform.

Indicating Instruments

8.01 Indicating electrical instruments are aids. They tell you whether or not voltage is present between two points. They are simple to use. They are not designed to measure the voltage, although some voltage testers indicate the approximate voltage present. A voltmeter should be used where precise measurement of voltage is needed.

8.02 The simplest indicating instrument is the light bulb. Light bulbs are used on control panels and pushbutton stations to indicate that power is on, or in some cases, the power is off. This is a visual indicating device. For identification, colored lenses may be used over the lamps to indicate what particular function a machine is performing at a given time.

Fig. 8-1. Incandescent test lamps.



8.03 A simple voltage tester can be made using light bulbs. This type of tester can be used for checking fuse panels to find a blown fuse. Two 120 volt bulbs in series can be used. The bulbs will light to full brilliance on a 220 volt circuit. On a 120 volt circuit, they will dim. For a 480 volt circuit, either four 120 volt bulbs or two 220 volt bulbs may be connected in series. Caution: This type testing device is not normally recommended on circuits above 120 volts, for safety reasons. Figure 8-1 shows the test lamps. A set of test lamps instead of a voltage tester can be kept near the fuse panel ready for immediate use. The test lamps can be used on either A-C or D-C circuits.

8.04 Sometimes neon, gas-filled bulbs (or glow lamps) are used. These bulbs can be used only where the voltage is 70 volts or higher. (The firing

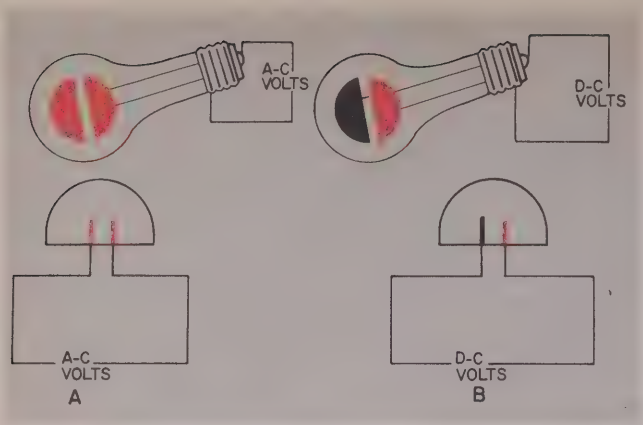


Fig. 8-2. Neon indicating lights.

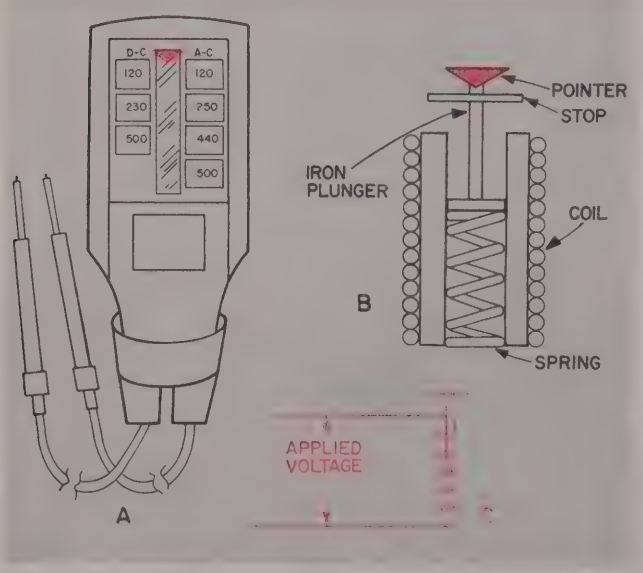
voltage for neon is about 70 volts.) The neon bulb has two electrodes but no filament. When the neon bulb is in an A-C circuit, both electrodes will glow, as illustrated in Fig. 8-2(A). A neon bulb across a D-C voltage will show only one electrode glowing, as shown in Fig. 8-2(B).

The Wiggy

8.05 The WIGGY, or wiggins, is a trade name given to the pocket-type voltage tester shown in Fig. 8-3(A). This name comes about from the way the tester operates. A pointer moves up and down a scale and vibrates or wiggles when put across a voltage source. This indicating instrument is very handy. It can be carried in your tool pouch, available for immediate use. It eliminates carrying a delicate voltmeter around.

8.06 The construction of the wiggy is shown in Fig. 8-3(B). The principle of operation is simple.

Fig. 8-3. Wiggy-voltage tester.

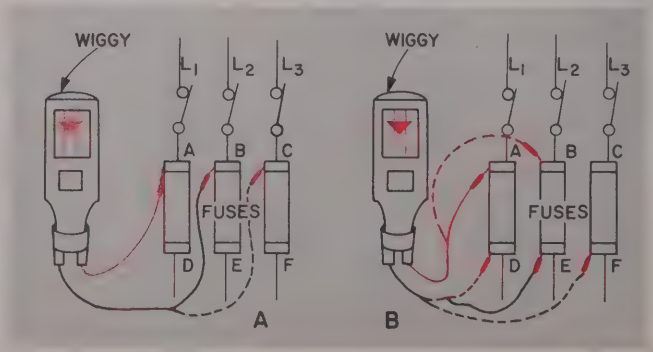


The basic component is a solenoid. When voltage is applied, current flows through the coil, which establishes a magnetic field. The magnetic field pulls the plunger downward, but plunger movement is against a spring. The spring allows the plunger to be drawn into the cylinder only a certain distance, according to the voltage applied to the coil. The pointer on the plunger indicates the voltage on the scale next to it.

8.07 The voltage-indicating scale on the tester has voltage indication for A-C on one side and D-C on the opposite side. The A-C voltage scale indicates 110-220-440-550 volts. The D-C voltage scale indicates 125-250-600 volts.

8.08 Here is an example of when and how you can use the wiggy. A machine in the finishing department is down. Your foreman sends you to locate the trouble. You locate the control panel, pull the disconnect switch and open the cover. The first procedure is to determine whether power is coming in to the switch. The switch disconnects the 480 volt 3-phase supply. Three 100 amp fuses are located in the switch enclosure. Trip the safety lock and throw the switch on. Using your wiggy, place one prod at point A shown in Fig. 8-4(A), touch the other prod to point B. The wiggy will indicate the presence of voltage by the pointer moving down. With voltage present between points A and B, remove the test prod from B and touch point C. Again an indication on the tester should show presence of voltage. If no voltage is present, then the trouble must be at the next protective device, nearer the source, which is feeding the circuit. A voltage check further down the line must be made to restore power to the switch, the same procedure should be followed. If voltage is present

Fig. 8-4. (A) Determining presence of incoming power with a wiggy. (B) Locating blown fuse using a wiggy.



between the points indicated then the next step is to find the blown fuse(s).

8.09 With one test prod at point A, touch point E, Fig. 8-4(B), with the other test prod for voltage between the two points. If no voltage exists, then the fuse is blown. Move test prod from point E to point F to determine if the fuse has blown. Remove the test prods and put one at point B and the other at point D. You have checked the three fuses. If no fuses are blown, then a check of the circuit downstream must be made for other possible causes of the trouble.

8.10 When any one fuse of a 3-phase system blows, it is good practice to replace all three fuses. Although one or two fuses show they have not blown, they may have heated to the point of being on the verge of blowing.

8.11 As an example – one fuse blows, and it is replaced, leaving the other two in the circuit. After checking the equipment and clearing the cause for fuse failure, the switch is thrown on and the equipment starts. Before the equipment gets running, a fuse blows, not the one that was replaced, but one of the others. Another period of downtime occurs while the fuse is replaced. Perhaps you replace all three fuses this time, even the new one you just put in. It is apparent that although nothing may be said, opinions of your performance may not be good.

8.12 Before replacing any fuses:

WARNING: PULL THE SWITCH. ALWAYS USE FUSE PULLERS to remove the fuses and to insert new fuses. NEVER USE PLIERS OR YOUR FINGERS. This is a dangerous practice.

Use these programed exercises to help check your learning progress.

8-1. Electrical indicating instruments are maintenance aids that indicate the presence of _____.	8-1. VOLTAGE REF: 8.01
8-2. The simplest electrical indicating instrument is the _____ _____.	8-2. LIGHT BULB REF: 8.02
8-3. Neon, gas-filled bulbs, called glow lamps, are frequently used as indicators where the voltage is at least _____ volts.	8-3. 70 REF: 8.04
8-4. A neon, gas-filled bulb has two electrodes but no _____.	8-4. FILAMENT REF: 8.04
8-5. The "Wiggy" is a shop name applied to a pocket-type indicating instrument for testing _____.	8-5. VOLTAGE REF: 8.05
8-6. The wiggy will indicate both _____ and _____ voltages.	8-6. A-C or D-C REF: 8.07
8-7. A wiggy can be used to locate blown _____.	8-7. FUSES REF: 8.08, 8.09
8-8. When one fuse of a 3-phase system blows, how many fuses should be replaced? _____	8-8. THREE REF: 8.10

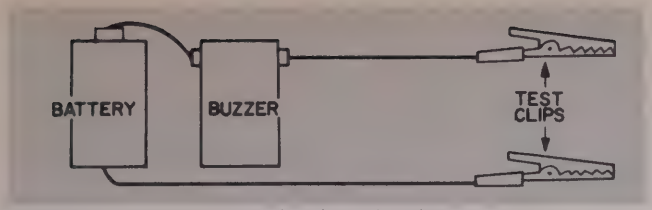


Fig. 8-5. Buzzer continuity checker.

Continuity Testers

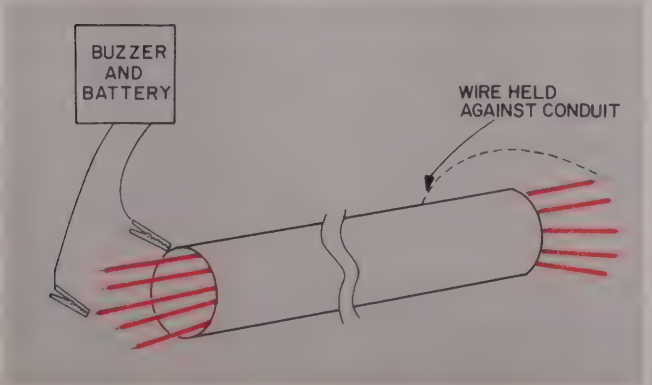
8.13 An ohmmeter can be used to check continuity, but this means carrying a delicate instrument with you. Pocket-type continuity testers are made commercially, but you can make one for yourself.

8.14 There are two types of continuity testers – audio and visual. The audio-type tester is a simple buzzer and battery with connecting leads, as shown in Fig. 8-5.

8.15 The buzzer battery combination continuity tester is used for ringing out wires. An example of its use is illustrated in Fig. 8-6. Several wires of the same color were pulled through a conduit. The wires must be identified before being connected to the circuit. At one end of the conduit, select one wire, strip the insulation so the bare wire can be attached to the conduit. At the other end of the conduit, clip one lead of the tester to the conduit. With the other lead, touch one wire at a time until the buzzer sounds. Put an identifying number (the same number) on both ends of the wire. Continue this procedure to identify the other wires.

8.16 A light bulb instead of a buzzer can be used as a visual indicator. The procedure for ringing out the wires is the same as for the buzzer.

Fig. 8-6. Ringing out wires with buzzer continuity checker.



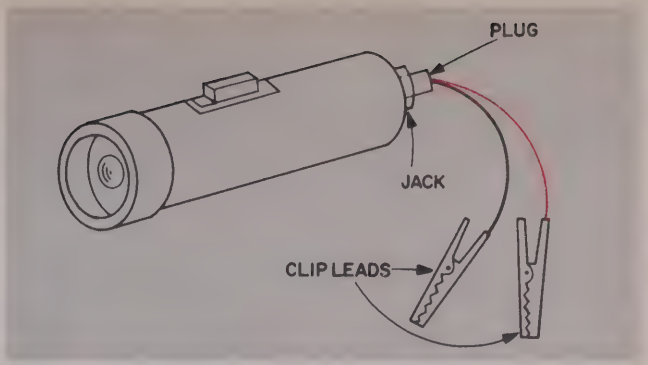


Fig. 8-7. Flashlight used as continuity checker.

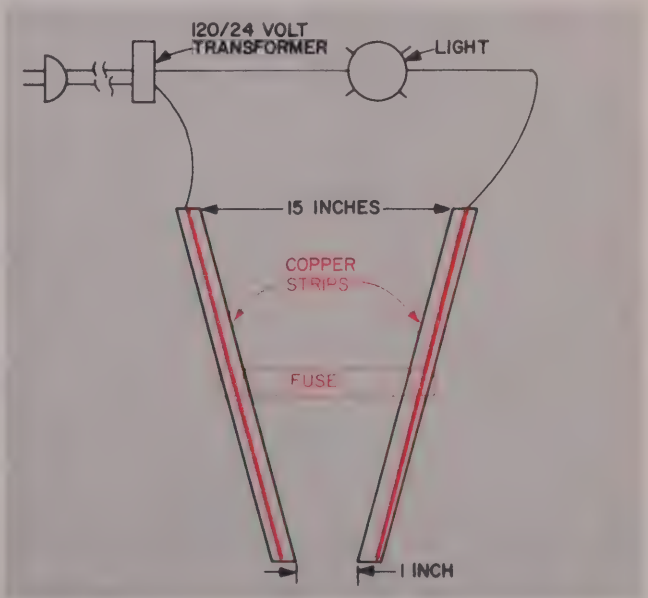
8.17 There is a flashlight available that can be used for checking continuity. The flashlight has a special cap with a jack into which a pair of test leads are plugged. When the test leads are shorted together, the light comes on. Since a flashlight is part of your tool kit, this type flashlight is ideal. It serves two purposes, and is always readily available for use. The flashlight is illustrated in Fig. 8-7.

8.18 Another continuity checker that is handy in the shop is the fuse checker. This is illustrated in Fig. 8-8. Two strips of copper, about ¼ to ½ inch wide and about 12 inches long, are fastened to a board in a "V" shape. The "V" enables you to check fuses of different lengths. To check a cartridge fuse, place the fuse across the bars as in Fig. 8-8. The light bulb glows if the fuse is good.

Rotation Tester

8.19 A rotation tester provides a means of ensuring the correct rotation of a 3-phase motor

Fig. 8-8. Cartridge fuse checker.



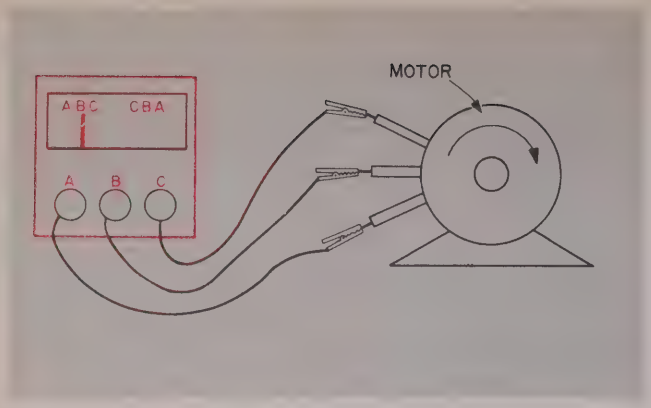


Fig. 8-9. Rotation tester.

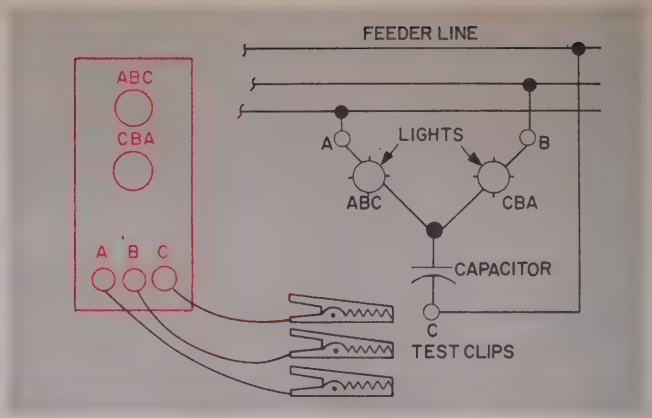


Fig. 8-10. Phase sequence indicator.

when it is first started. Proper use of the tester eliminates temporary connections or reconnection of leads, and helps prevent possible damage to the driven machinery from driving it the wrong way. The tester leads are connected to the motor leads, as illustrated in Fig. 8-9. The motor is rotated by hand in the correct direction. The deflection of the meter needle will tell whether the phases are A-B-C sequence. Tag the leads when the correct sequence is obtained. The motor leads are connected to the supply lines in the same order.

Phase Sequence Indicator

8.20 It is necessary to maintain correct phase sequence in a polyphase system. All feeders and branch circuits in a distribution system must be properly interconnected to prevent damage or improper operation. The connections must be phase A to phase A, phase B to phase B, and phase C to phase C.

8.21 To determine proper phase sequence, a phase sequence indicator is used. It determines the phase relationship of any energized 3-phase line. The instrument, shown in Fig. 8-10, consists of two light bulbs and a capacitor connected in a Y. A test lead is connected to each leg of the Y. The lamps are labeled A-B-C and C-B-A, the two possible phase combinations. The three leads are connected to a 3-phase line; one lamp will burn more brightly than the other. The brighter light indicates the phase sequence.

8.22 The phase sequence of the 3-phase motor leads is determined with a rotation tester. The phase sequence of the motor branch circuit is determined with the phase sequence indicator. These two devices ensure correct connection of the motor leads to the feeder so the motor rotates in the proper direction.

8-9. There are two kinds of continuity testers. One indicates by _____ means, and the other by _____ means.	8-9. AUDIO and VISUAL REF: 8.14
8-10. A continuity tester is used to identify wires in a conduit by a method called _____ out the wires.	8-10. RINGING REF: 8.15, 8.16
8-11. A flashlight can be used as a continuity tester when it is equipped with a special _____ for test leads.	8-11. JACK REF: 8.17
8-12. A fuse tester indicates a fuse is good when the lamp _____.	8-12. GLOWS REF: 8.18
8-13. The phase sequence of 3-phase motor leads is determined with a _____ _____.	8-13. ROTATION TESTER REF: 8.19, 8.22
8-14. When using a motor rotation tester, the motor is rotated in the proper direction by _____.	8-14. HAND REF: 8.19
8-15. The phase relationships of any energized 3-phase line can be determined with a _____ _____ indicator.	8-15. PHASE SEQUENCE REF: 8.21
8-16. The brighter light on the phase sequence indicator indicates the _____ _____ (either A-B-C or C-B-A).	8-16. PHASE SEQUENCE REF: 8.21

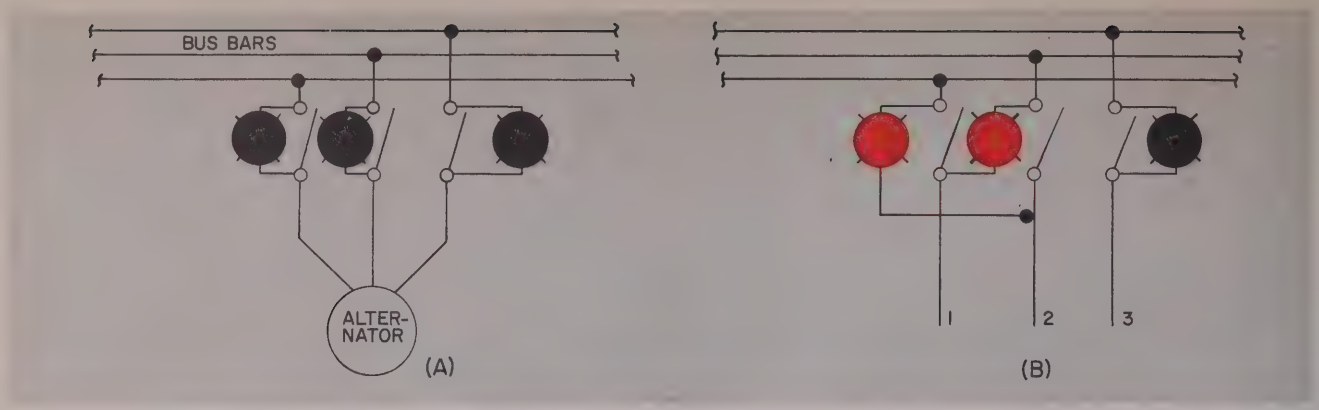


Fig. 8-11. Connections for (A) three-dark method and (B) two-bright and one-dark method of synchronizing with lamps.

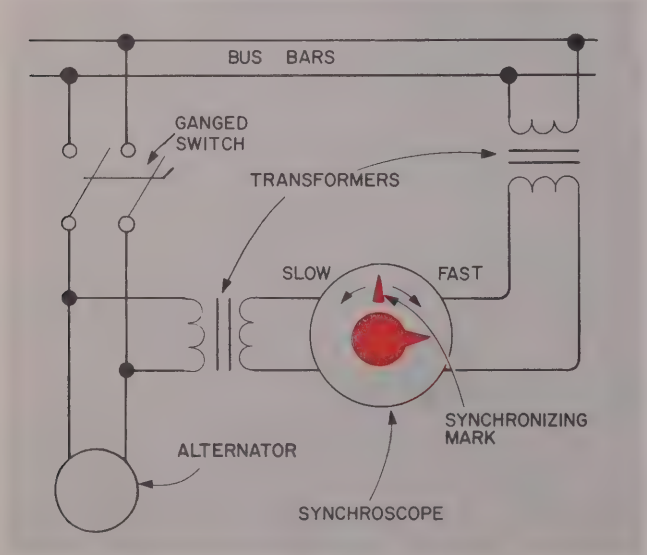
Synchronizing

8.23 Two conditions must be met before alternators can be electrically connected in parallel with safety. The terminal voltages must be equal and the proper phase sequence must be observed. This ensures that each phase polarity of each generating unit is in step or in unison with the other unit or units.

8.24 A voltmeter determines the equality of the voltages. The voltmeter does not give any indication of the instantaneous polarity. The indications of an A-C voltmeter are independent of polarity.

8.25 Lamps can be used to determine the correct polarity. Figure 8-11(A) shows the connections for phasing a 3-phase alternator with the bus bars. A lamp is connected across each pole of a 3-pole switch that connects the alternator to the bus bars. The lamps become bright and then dim together.

Fig. 8-12. Synchroscope connection.



8.26 When the lamps are bright, the alternator and bus line voltages are additive. When the lamps are dark, the alternator and bus line voltages oppose each other, and are thus neutralized. This varying phase displacement of the two sets of voltages causes the lamps to flicker at a rate equal to the difference in the frequencies of the alternator and the bus bars. As the frequency of the alternator approaches that of the bus bars, the flicker becomes slower. When the lamps are dark, the switch is thrown. The two alternators are in parallel.

8.27 There is a disadvantage to this method. An incandescent lamp can be dark even though a considerable voltage difference exists across the terminals.

8.28 This difficulty can be eliminated by cross-connecting two of the lamps, as shown in Fig. 8-11(B). When the alternator and bus bars are in synchronism, lamp 3 is dark, while lamps 1 and 2 are bright. As one of the lamps is increasing, the other is decreasing in brilliance. Near the point of synchronism, the switch should be closed. This method of two-bright-one-dark is more accurate than the three-dark method of synchronizing.

The Synchroscope

8.29 In practice, alternators are synchronized by using a synchroscope. A synchroscope is an instrument that indicates when the alternators are in phase for parallel connection. This instrument also

shows whether the incoming alternator is running fast or slow.

8.30 A simplified circuit using a synchroscope is shown in Fig. 8-12. If there is a difference between the frequencies of the incoming alternator and running alternator, the pointer rotates at a speed which is equal to this difference. The direction of the pointer's rotation indicates whether the incoming alternator is fast or slow. The alternator switch is thrown when the pointer is rotating slowly in the fast direction and is approaching the synchronizing mark located at the 12 o'clock point on the synchroscope dial. The point of the synchroscope will remain stationary after the alternator is paralleled.

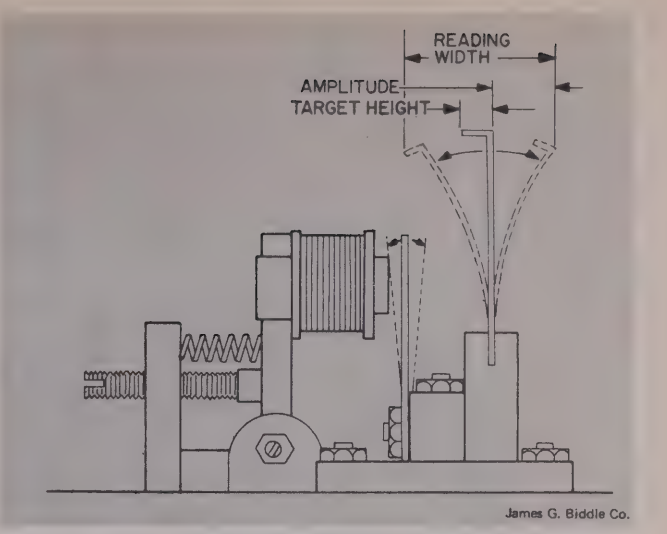


Fig. 8-13. A vibrator type meter and an actuating system.

Frequency Meters

8.31 If electricity were used only for incandescent lighting, the problem of maintaining and indicating correct frequency would be of little concern. But most motors depend upon correct frequency for their rated speed. Transformers depend upon correct frequency for efficient operation. Electric clocks and timing devices depend upon frequency for their accuracy. Therefore, some type of instrument is required to indicate the frequency of the system.

8.32 A frequency meter indicates, in cycles per second, the frequency of the electrical supply system. Although frequency meters are used at power plants, they can be used to monitor line frequency at any point in the system. Plant emergency or stand-by generating equipment has frequency meters so correct frequency is maintained when emergency power is required. The operator or maintenance electrician adjusts the controls of the generating equipment for proper voltage and frequency output.

8.33 Electric utility companies require frequency meters that indicate frequency to a fraction of a cycle-per-second without being affected by normal variations in the system voltage.

8.34 Since the operating frequency in this country is standard at 60 Hz, frequency meters need to cover only a narrow band on either side of the normal frequency. This narrow band allows the instrument to be more accurate than it would be if it was required to measure a wide area of frequencies.

8.35 There are several types of frequency meters available. A "resonant reed" frequency meter is shown in Fig. 8-13. The instrument has tuned steel reeds, which indicate alternating current frequency by resonance. The principle applied here is similar to that of a harmonica. When you blow into a harmonica, the reeds vibrate and give off certain tones. In the frequency meter, several reeds are made to vibrate at a certain tone or frequency.

8.36 The tips of the reeds are displayed through an opening in the face of the meter. A scale is placed adjacent to the opening, and calibrated at half-cycle intervals. The normal or standard frequency (60 Hz) is in the center. This is shown in Fig. 8-14.

8.37 The frequency meter described is one of the more popular types. There are other types, such as the "resonant-circuit" frequency meter; another incorporates electronic circuits with direct digital readout.

The Growler

8.38 No, this is not about your boss, although he may remind you of some type of indicating instrument at times. The GROWLER is an indicating instrument used to detect and locate grounded, shorted, and open coils in a motor or generator armature. The use of the armature in electrical equipment is explained in Unit 6.

Fig. 8-14. A vibrating reed frequency meter.

How to Read the Scale

Simply read the scale adjacent to the predominantly vibrating reed or reeds. Clear, quick-reading scales permit anyone, with a little practice, to make accurate measurements without difficulty.

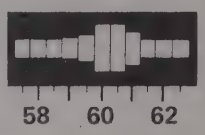
READ DIRECTLY IN Hz

Reading can be easily made to one quarter of the interval between reeds providing the basic interval is on the order of 1% or less, keeping in mind our response curve is symmetrical.

READING 60.0

The individual reeds are guaranteed to within ±0.3% at 25°C in the standard instruments and to ±0.1% in the precision instruments.

READING 60.25



In the examples at the right the interval between reeds is ½ cycle. The visible pattern of vibrating reeds indicates, on the adjacent scale, the frequency being measured. With a little practice, readings can be made quickly and easily to one quarter of the interval between reeds.

READING 60.125

James G. Biddle Co.

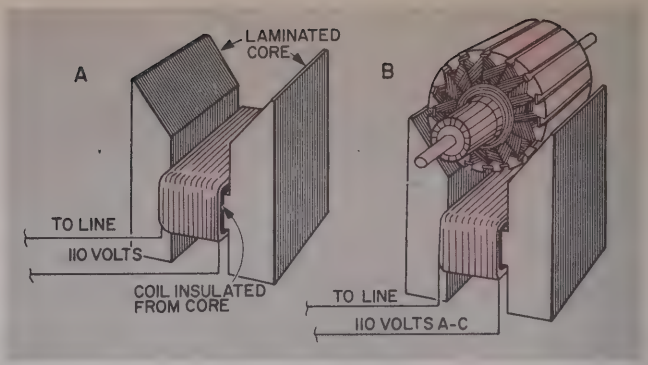


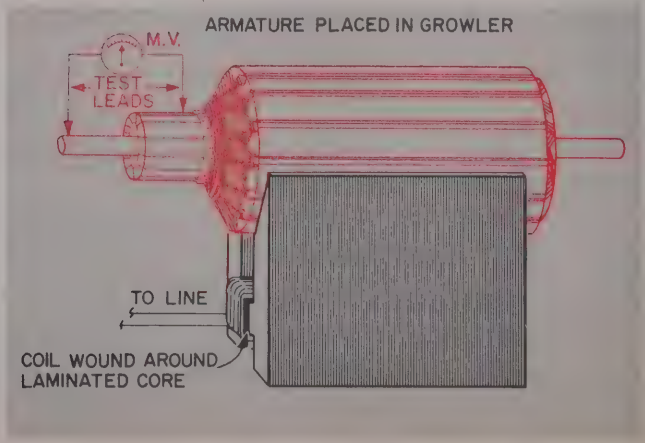
Fig. 8-15. (A) A growler consisting of a coil wound around a laminated core. (B) An armature in position on a growler for test purposes.

8.39 Basically, the growler is the primary side of the transformers shown in Fig. 8-15(A). When an armature is placed in position, Fig. 8-15(B), it becomes the secondary of the transformer.

8.40 The growler consists of a coil of wire wound around a laminated iron core. The coil is connected to a 120 volt A-C source. The core is H-shaped and formed to accommodate an armature. When A-C is applied to the coil, voltage is induced in the armature coils by transformer action.

8.41 To test an armature for grounds, place the armature on the growler and apply 120 volt A-C power. Using an A-C millivoltmeter, place one lead on the top commutator bar and the other lead on the armature shaft, as illustrated in Fig. 8-16. A reading on the meter should be obtained. Turn the armature to bring the next commutator bar on top. Proceed with the readings. When no reading is obtained, a grounded coil is connected to the

Fig. 8-16. The growler is used to locate grounded coil.



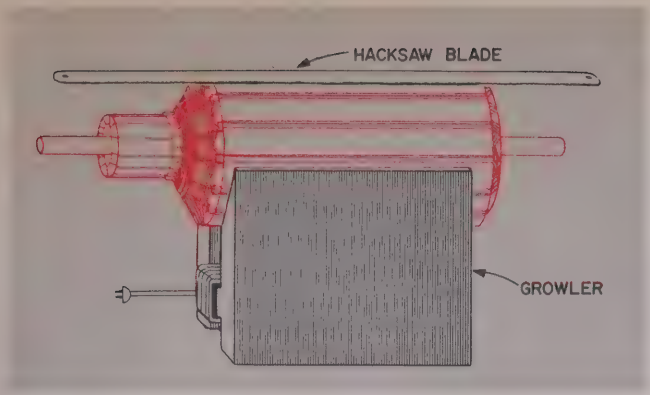


Fig. 8-17. Testing an armature for shorts with a hacksaw blade.

commutator bar on top. Mark the bar for identification.

8.42 To test an armature for a short circuit (shorted turns), place the armature on the growler and apply power. Hold a thin piece of steel, such as a hacksaw blade, over the top slot of the armature, as shown in Fig. 8-17. The blade is held directly over and along the length of the slot. If the coil in this slot is shorted, the blade will vibrate and create a growling noise, thus the name growler.

8.43 After several top slots have been checked by the hacksaw blade test, turn the armature to bring the other slots to the top. Continue this procedure for the entire armature. Mark the slots, where the hacksaw blade vibrates.

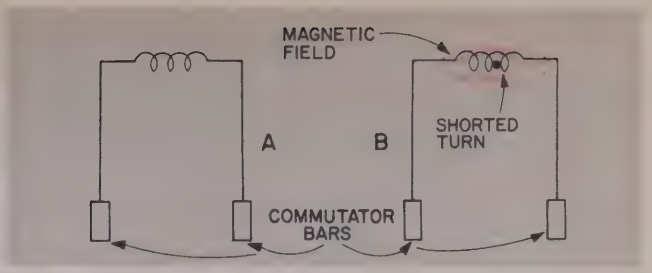


Fig. 8-18. Armature coils: (A) normal, (B) shorted turn.

8.44 The start and finish ends of a coil are connected to the copper bar segments of the commutator. The coil is essentially an open circuit as shown in Fig. 8-18(A). When a voltage is induced in the winding by the growler, no current will flow.

8.45 If a turn or turns of a coil are shorted together, an electrical path is completed. When voltage is induced in the shorted coil by the growler, current will flow, as shown in Fig. 8-18(B). The flow of current produces a magnetic field. This magnetic field attracts the hacksaw blade when held over the armature slot in which the shorted coil is contained and you get a growl.

Use these programed exercises to help check your learning progress.

8-17. One method of synchronizing alternators is the three _____ lamp method.	8-17. DARK REF: 8.26
8-18. A more accurate method than the three dark lamp method is the two _____ one _____ method.	8-18. BRIGHT, DARK REF: 8.28
8-19. In general practice, alternators are synchronized by using a _____.	8-19. SYNCHROSCOPE REF: 8.29
8-20. On a synchroscope, the direction of the pointer rotation indicates whether the incoming alternator is running too _____ or too _____.	8-20. FAST or SLOW REF: 8.30
8-21. What type indicating instrument should you use to determine the frequency of an electrical power supply from an A-C source? _____	8-21. FREQUENCY METER REF: 8.32
8-22. A growler is an instrument used to detect and locate grounded, shorted, and open coils in a motor's or generator's _____.	8-22. ARMATURE REF: 8.38
8-23. An A-C millivolt meter and a growler are used when testing an armature for _____.	8-23. GROUNDS REF: 8.41
8-24. A hacksaw blade held over a slot on an armature seated in a growler locates _____ coil turns.	8-24. SHORTED REF: 8.42

SELF-CHECK QUIZ

8-1. What is the most simple electrical indicating instrument used on a control panel?

a. D-C voltmeter
b. A-C ammeter
c. Synchroscope
d. Light bulb

8-2. A bulb-type voltage tester is recommended only for circuits at or under

a. 120 volts
b. 240 volts
c. 480 volts
d. 600 volts

8-3. The pocket-type tester, sometimes called the "Wiggy," is used to indicate approximate

a. current
b. resistance
c. voltage
d. impedance

8-4. A pocket-type voltage tester will indicate

a. D-C voltage only
b. A-C voltage only
c. A-C or D-C voltage
d. both voltage and resistance

8-5. When ringing out the wires in a conduit for identification, use a/an

a. voltmeter
b. ammeter
c. megohmmeter
d. continuity tester

8-6. A rotation tester is used to determine the phase sequence of the leads for a/an

a. single phase motor
b. D-C motor
c. 3-phase motor
d. A-C or D-C motor

8-7. A phase sequence indicator is used to determine the phase sequence of any energized

a. 3-phase line
b. single phase line
c. D-C line
d. telephone line

8-8. When synchronizing alternators with the lamp method, which of the following is most accurate?

a. Three bright lamps
b. Three dark lamps
c. One bright, two dark lamps
d. Two bright, one dark lamp

8-9. Electric utility companies require frequency meters that indicate frequency within

a. one cycle-per-second
b. two cycles-per-second
c. 60 cycles-per-second
d. a fraction of a cycle-per-second

8-10. Grounds, shorts, and opens in small motor or generator armatures can be easily detected with a/an

a. armature bridge
b. growler
c. point-to-point test
d. armature coil detector

ANSWERS TO SELF-CHECK QUIZ

8-1. d. Light bulb. REF: 8.02.

8-2. a. 120 volts. REF: 8.03.

8-3. c. Voltage. REF: 8.05.

8-4. c. A-C or D-C voltage. REF: 8.07.

8-5. d. Continuity tester. REF: 8.15.

8-6. c. 3-phase motor. REF: 8.19, 8.22.

8-7. a. 3-phase line. REF: 8.21.

8-8. d. Two bright, one dark lamp. REF: 8.28.

8-9. d. A fraction of a cycle-per-second REF: 8.33.

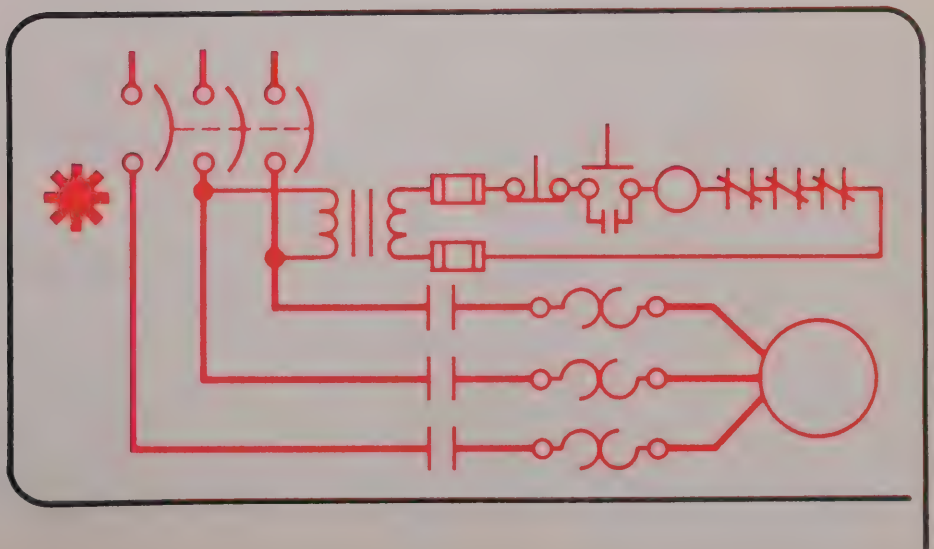
8-10. b. Growler. REF: 8.38.

LESSON NINE

RECORDING INSTRUMENTS AND INSTRUMENT CARE

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Nine — Recording Instruments and Instrument Care

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Lesson Nine — Recording Instruments and Instrument Care

Preface

Frequently it is necessary or important to know the conditions existing in an electrical circuit over a period of time. "Recording" instruments provide this detailed record unattended. Recording instruments are an integral part of our modern technology.

As explained in this unit, the forces that operate electrical measuring instruments are extremely small, and the instruments are necessarily of delicate construction. Certain precautions must be taken to avoid damage to the instruments, which naturally results in reading errors.

This lesson explains recommended practices for proper care of instruments.

This lesson explains the common types of instruments that record electrical quantities. This lesson also explains the principles and uses of the stroboscope. Stroboscopic techniques used in industry are also included.

The stroboscope is not a new device. It was invented in 1832 by a Mr. Stampfer of Vienna, who called his invention a "stroboscope," which is derived from the Greek words meaning "whirling disks" — a perfect description of the first stroboscopes. They were "whirling" disks with slots at regular intervals. The "watcher" looked through the slots to view an object. What he saw was interrupted by the disk, thereby producing a stroboscopic effect.

Recording Instruments

9.01 "Recording instruments," is a term used to describe many instruments that make a record of quantities over a period of time. Recording instruments include:

1. Instruments that record ELECTRICAL QUANTITIES; volts, amperes, watts, power factor, frequency, and so on.

2. Instruments that record NONELECTRICAL QUANTITIES through the application of ELECTRICAL SYSTEMS; temperature recorders that employ a potentiometer system to record thermocouple output.

3. Instruments that record NONELECTRICAL QUANTITIES by MECHANICAL MEANS; temperature recorders in which the expansion of liquid in a closed system actuates a pen.

9.02 In many instances, it is desirable to know the conditions existing in an electric circuit, but it is neither practicable nor economical to assign a man to watch indicating instruments and record

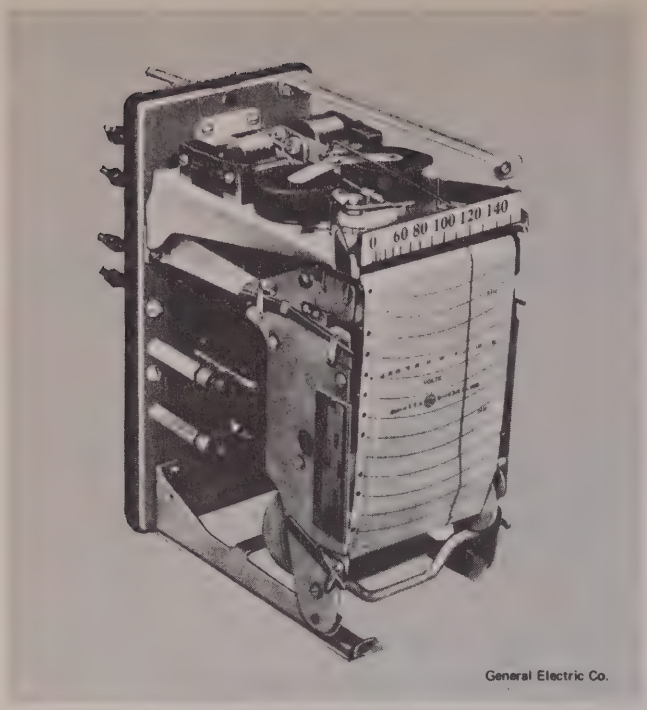


Fig. 9-1. Recording voltmeter.

their readings. Therefore, recording instruments, which provide a record of the actual circuit conditions existing at a definite time, have been developed.

9.03 Instruments in which the recording is made on a photographic film or on light-sensitive paper are not included in this lesson.

9.04 Recording instruments are similar to indicating instruments in many ways. They use the same electrical mechanisms, they are made of substantially the same principal parts, and they normally include a fixed visual scale on which the pointer indicates the magnitude of the quantity being measured. A recording instrument is basically a meter used with a recording mechanism. Meter circuit connections are made in the same manner as connections for indicating instruments, with an additional input for the recording mechanism.

9.05 Recording instruments differ from indicating instruments in that the pointer, besides indicating the measured quantity on the fixed scale, provides a graphic record on a chart which moves past a pen at a constant speed.

9.06 Recording instruments are more highly damped than indicating instruments. Since overshooting of the pen is undesirable, the instrument damping is set at a value that prevents overshoot, without unduly slowing the response.

9.07 The most widely used recording instruments for electrical measurement are strip-chart recorders – so called because the record is made on a strip of paper usually four to six inches wide and up to sixty feet long. A typical recording instrument is illustrated in Fig. 9-1.

9.08 These instruments offer many advantages in electrical measurement. The long charts allow the recording to cover a considerable period of time, with minimum attention required. Also, the strip-chart can be operated at relatively high speed to provide a very detailed record. To obtain high accuracy, the instruments are made large enough to allow the use of comparatively large, high-torque moving elements.

Strip-Chart Recorders

9.09 The FRAME supports the various parts of the instrument, and the MOVING SYSTEM comprises those parts that move as a direct result of the variation in the electrical quantity being measured.

9.10 The GRAPHIC RECORD is traced on the chart. The CHART CARRIAGE comprises the clock mechanism, the time rate gears, the timing drum, the chart spool, the reroll mechanism, and the writing table.

9.11 A FIXED SCALE is provided on which the value of the quantity being recorded is indicated.

9.12 The INKING SYSTEM consists of a special type of pen, and an ink reservoir.

9.13 The CASE includes features for convenience in installing and removal, as well as renewal of the chart. Recording instruments are constructed in cases suitable for both portable service and switchboard installation.

9.14 The moving systems used in recording instruments are basically the same as those used in indicating instruments for measuring the same quantities. They are, however, larger and they require more power because of the added load imposed by the friction of the pen on the chart. To minimize this load, and to obtain the correct

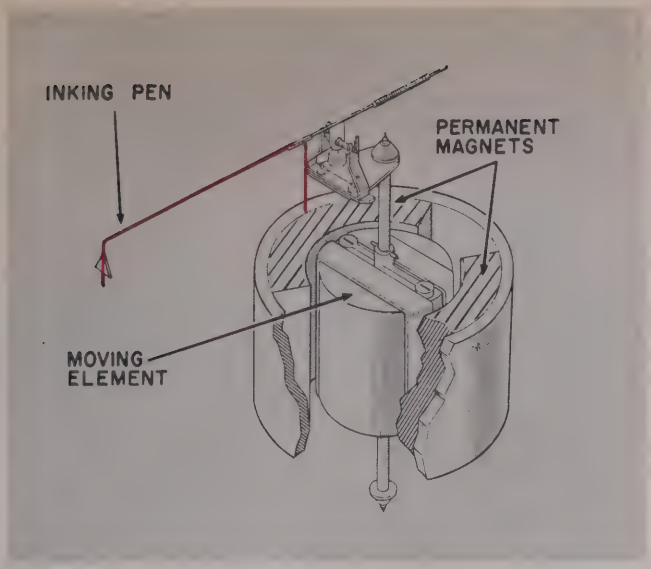


Fig. 9-2. P-M mechanism for a D-C recording instrument.

"touch" of the pen on the chart paper for best writing, the pen is carefully counterbalanced. The pen is easily removed for cleaning. Figure 9-2 illustrates a typical moving system for a D-C recorder.

9.15 The chart, on which the graphic record is made, is graduated in two directions: in one direction, the graduations correspond to the fixed scale of the instrument; in the other direction, the graduations correspond to terms of time. They may be seconds, minutes, hours, or days, depending on the clock mechanism. The time graduations are uniformly spaced because the chart speed is constant. Measuring-scale graduations are substantially the same in comparable indicating instruments.

9.16 The paper used for charts is especially selected for the best performance under varying temperature and humidity conditions.

9.17 The chart carriage includes the entire mechanism for handling the paper chart. At the top, it holds the roll of chart paper on which the record is made. Just above the roll and directly beneath the pen is the writing table, which is a flat metal plate over which the chart passes. The writing table provides a flat surface for the chart at all points of the arc of the pen.

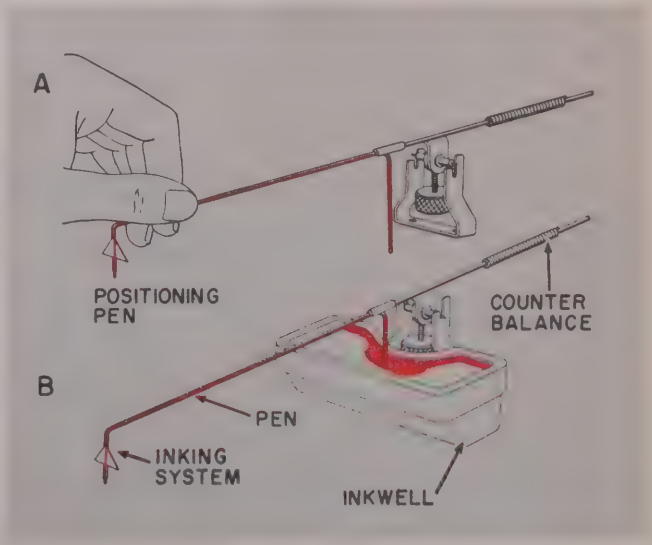
9.18 The heart of the chart carriage is the timeclock mechanism, which drives the timing drum. The timeclock can be an electric clock of the synchronous-motor type; it can be of the spring type, hand-wound; or it can be kept constantly wound by a small electric motor. The latter type combines the convenience of an electrical chart drive with the assurance that failure of the auxiliary power source will not arrest the motion of the chart until the spring mechanism runs down. This permits a power interruption of several hours with no effect on the operation of the recording instrument.

9.19 The timing drum is connected to the timeclock through a gear unit which governs the speed of drum rotation. The gear unit also provides a constant speed to the chart by means of drive pins that are evenly spaced around the circumference of the timing drum, and which engage holes in the side of the chart. Some charts have these drive holes along only one side; others have holes along both sides.

9.20 The INKING SYSTEM usually has an inkwell containing a quantity of special recording ink sufficient for a considerable period of time, and a pen. The back end of the pen is provided with a counterweight to permit adjustment for the correct "touch" of the writing pen on the paper.

9.21 One end of a capillary tube rests in the inkwell, and, by capillary action, it carries ink to the writing tip. The writing tip is made of a special metal-alloy that can withstand both the wear of

Fig. 9-3. Inking system for a recording instrument.



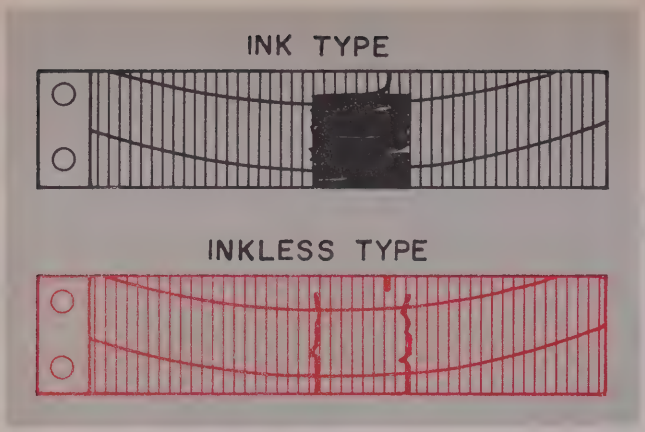


Fig. 9-4. Ink vs inkless records.

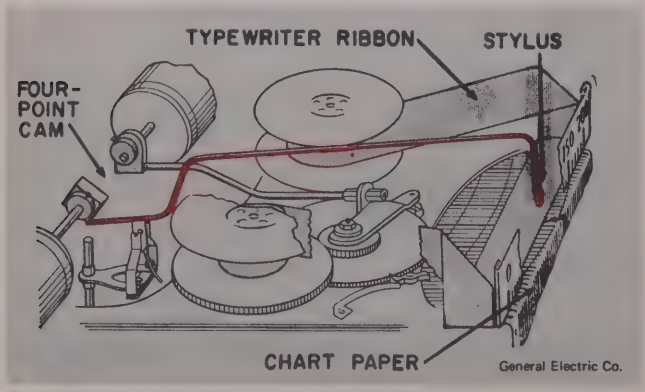
continued friction on the chart and the corrosive action of the ink itself.

9.22 The ink used in recording instruments is a special type, which is compounded to give the required performance under the operating conditions in which recorders are used. A typical inking system is illustrated in Fig. 9-3: (A) shows the pen being set into the operating position, and (B) shows the pen and inkwell in the operating position.

Inkless Recorders

9.23 It is the primary requirement for a recording instrument that it produce a legible record under all service conditions. The pen and ink method is not wholly satisfactory for some requirements. When the quantities being measured fluctuate violently, a "painting" effect is produced. To overcome this disadvantage, the inkless recorder is used. The inkless recorder produces a series of dots that are close enough together to provide a continuous line without the "painting" effect. Where the ink would make a poor record, the

Fig. 9-5. Inkless recording unit.



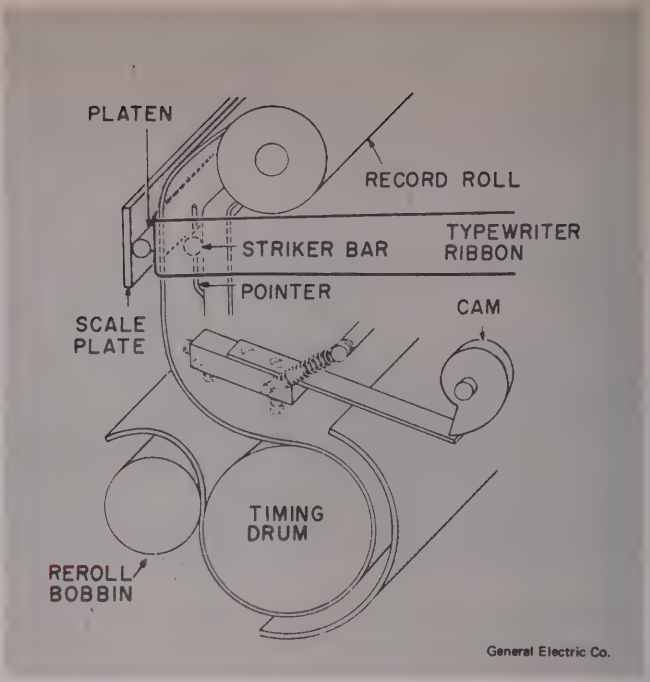


Fig. 9-6. Chart paper feed mechanism for an inkless recorder.

inkless record shows a clearly detailed outline of the operating-current value. A comparison is shown in Fig. 9-4.

9.24 In some recording instruments, an inkless recording unit replaces the conventional inking system. The chart carriage and scale are basically the same as those used in the ink recorder. A typewriter ribbon is fed through suitable guides across the chart just above the writing table as illustrated in Fig. 9-5. The pen is replaced by a stylus which fits into the pen clips on the element. A synchronous motor drives a four-point cam which strikes the rear end of the stylus directly over the center of rotation of the moving element. The stylus taps the chart, thus producing the record. A diagram of an inkless recording instrument paper feed mechanism is shown in Fig. 9-6.

Round-Chart Recorders

9.25 Instruments for recording electrical quantities are also manufactured in a style in which the record is produced on a round chart.

9.26 Round-chart instruments are used in applications which do not require the long, continuous record provided by strip-chart recorders, or where it is more convenient to keep daily records or individual records. In such applications, another

Fig. 9-7. Round-chart recorder.

advantage is the entire chart is visible at all times, thus permitting the record to be observed without opening the instrument case and pulling the chart out.

9.27 The round-chart recorder uses basically the same principal parts as the strip-chart instruments, except that no fixed scale is provided because the value of the measured quantity can be read directly on the chart scale, as illustrated in Fig. 9-7.

9.28 The torque-producing element can be a solenoid. This type of element permits the instrument to operate on either direct or alternating current, although it must be calibrated for each. Magnetic damping is used to stabilize the movement of the pen arm.

9.29 The chart is normally 8, 10, or 12 inches in diameter. The graduations corresponding to the measured quantity are concentric circles on the chart. Because of the characteristic of the solenoid element, the scale is not uniform but crowded as it approaches the center of the chart. The time graduations are extended radially around the chart, resulting in crowding of the time scale as it approaches the center of the chart.

9.30 Common chart speeds are set for one revolution in 24 hours or for one revolution in seven days; hence, the round-chart instrument is *not* well-suited to applications in which the instrument is unattended for long periods of time.

9.31 The inking system used with round-chart recorders differs from that used with strip-chart recorders. The ink reservoir is made as an integral part of the pen, and it takes the form of an open trough. A metal capillary tube serves as the writing tip.

Use these programed exercises to help check your learning progress.

9-1. What is the most important advantage of recording instruments over ordinary electrical instruments? _____ _____	9-1. Provides a record of conditions at certain periods without having to be watched. REF: 9.02
9-2. Except for the addition of a recording mechanism, which provides a permanent record, recording instruments and indicating instruments use the same _____ _____.	9-2. ELECTRICAL MECHANISMS REF: 9.04, 9.05
9-3. Two primary advantages of strip-chart recorders are: 1. _____ 2. _____	9-3. 1. They record for long periods of time; 2. They provide a detailed record REF: 9.08
9-4. Recorder charts are graduated in two directions. The values are: 1. _____ 2. _____	9-4. 1. TIME (minutes, hours, days). 2. FIXED SCALE OF THE INSTRUMENT (volts, amps, watts, etc.) REF: 9.15
9-5. The three most common drive mechanisms for electrical recording instruments are: 1. Hand-wound springs; 2. Synchronous electric motors; and 3. _____ _____	9-5. SPRINGS WOUND BY SMALL ELECTRIC MOTORS REF: 9.18
9-6. What type of recording ammeter should you select if the currents you plan to measure are expected to fluctuate widely within a short time span? _____ _____	9-6. Select an INKLESS type to avoid the "painting" effect of the ink-type recorder REF: 9.23
9-7. If you plan to keep daily records, or need to see the entire record at one time, you should select a _____ chart recording instrument.	9-7. ROUND REF: 9.26
9-8. Round-chart recording instruments are of greatest value when a record is needed over a _____-hour period, or for _____ days.	9-8. 24-hour, or 7 days REF: 9.30

Care of Instruments

9.32 Instruments serve an important function in the maintenance of all types of electrical equipment. The following paragraphs explain their care and how they should be used. Proper selection of instruments ensures the best results.

9.33 Instructions and wiring diagrams are furnished with most instruments. The instructions are either attached to the instrument case or cover, or given in a separate booklet. These should be consulted for specific instructions and precautions.

Instrument Operating Care

9.34 To avoid damaging the pivots of the moving elements or jeweled bearings, instruments should be handled with care and not subjected to shock or blows. When transporting instruments, they should be carried in a vertical position so the shafts of the moving elements are in a horizontal position. Chances of damage to the bearing systems are then lessened.

9.35 Carry only one instrument in your hand at a time to prevent damage. If a locking device has been provided for the moving element, it should be operated before the instrument is moved.

9.36 Instruments should be gently lowered, not dropped, into the carrying cases.

9.37 When storing or moving a recording instrument, the ink should be removed from the inkwell, the pen cleaned, the moving element locked and the chart carriage secured.

9.38 Precaution should be taken to ensure that the current or voltage to be measured is within the range of the instrument to be used. If the range of quantities to be measured is not known, a high-range instrument should be connected first, to get an approximate indication of the value, after which an instrument with the proper range may be used. Readings should be made directly facing the scale so that the pointer and its line-of-sight are the same.

9.39 Always try to have the instrument reading at a point about two-thirds full-scale value. Instrument accuracy is always expressed in terms of the percentage of error at the full-scale point, so maximum accuracy is obtainable by keeping the reading as high on the scale as possible. Selection of a properly rated instrument is important.

9.40 Do not use fused instruments, or place fuses in the instrument circuit when connecting instruments into the secondary of a current transformer. If the fuse blows, it can result in high voltages across the secondary.

9.41 A zero shift caused by a bent pointer should be corrected by straightening the pointer rather than by the zero adjustment. In this connection do NOT remove the case or cover from the instrument except in a meter repair shop.

9.42 Temperature effects are inherent in almost all electrical instruments, and they are caused by exposure of the instrument to temperature extremes or by self-heating during use. If the instrument has been exposed to unusual heat or cold for some time, it should be exposed to room temperature until the temperature of the instrument is approximately normal.

9.43 Temperature errors caused by self-heating are minimized by leaving the instrument in the circuit as short a time as possible.

9.44 Excessive temperature may permanently impair the accuracy of an instrument from permanent magnetic effects in the magnet of permanent-magnet, moving-coil instruments, in the iron parts of moving-iron instruments, or in the magnetic materials used to shield instruments from disturbance by stray magnetic fields. Electrical measuring instruments should NEVER be placed in, or carried through, a strong magnetic field.

9.45 Since it is often not known if strong stray magnetic fields are present in the test area, the instrument should be read, turned 180 degrees, read again, and an average taken of the test readings. If an instrument is to be permanently used on magnetic panels (iron or steel), the instrument should be calibrated either on-location or with an equivalent panel.

9.46 A heavy short circuit in conductors near an instrument, even though of extremely short duration, can partially demagnetize the permanent

magnet in a direct current instrument. After such an occurrence, instruments near the short-circuited conductors should be checked for accuracy even if they have suffered no visible injury.

9.47 Unshielded instruments should not be placed close together because the reading of one instrument may be affected by the magnetic field of the other.

9.48 If an instrument is overloaded or dropped, or, if for any reason the accuracy is in doubt, the instrument should be checked against another instrument, at several points, before it is used again.

9.49 When a split-core current transformer is used with an ammeter, always be sure that the transformer-core joints are free from dirt. Dirt introduces errors into the readings.

9.50 Special instruments should be used to measure motor-starting currents and welding currents.

9.51 Clean the glass of an instrument, using only a *damp* cloth. A dry cloth can induce a static charge, which affects the instrument reading. (If the instrument glass does become charged, it can be discharged by breathing on it.)

Instrument Correction Precautions

9.52 The coils of electrical measuring instruments are of limited current-carrying capacity. They can be burned out with startling rapidity by excessive current. To avoid such an occurrence and errors because of loose or dirty connections, keep the following points in mind when connecting instruments:

Whenever possible, connections should be made only when the circuit is not energized.

All contact surfaces must be clean.

All connections must be tight.

An ammeter, or the current coil of a wattmeter of other current-measuring instrument, must be connected in series and NEVER across the line carrying the current to be measured. If an external shunt or current transformer is required, the shunt or the primary of the current transformer must be connected in series with the line.

9.53 When a voltmeter or the potential coil of a wattmeter or other instrument is to be connected, it must be connected across the voltage to be measured, and in series with an external multiplier if one is used, or across the secondary of a potential transformer. When a potential transformer is required, the primary is connected across the voltage to be measured.

9.54 The secondary of a potential transformer should be open circuited or closed through a voltmeter or potential coil, when the primary is energized, and NEVER short-circuited or closed through a low resistance.

9.55 When a voltmeter is to be connected to a circuit, always connect the leads to the instrument first. This avoids "hot" leads. Be sure that voltmeter leads are properly insulated for the voltage to be checked.

9.56 When a potential transformer is used, its secondary circuit must be grounded. Always make sure that the instrument is connected to the secondary, or low-voltage, winding. Cut off line voltage before making primary connections.

9.57 When a current transformer is used, its secondary circuit must be grounded. Always make sure that the secondary circuit is never opened while current is flowing in the primary winding, or dangerously high secondary voltage will result. The secondary winding should be short-circuited when changing instruments, or when not in use. Cut off line voltage before making primary connections.

9.58 When rectifier instruments are used in A-C circuits to measure A-C values, the waveform should be known, because rectifier instruments are normally calibrated on sine wave A-C circuits.

9.59 Instruments, shunts, and leads should always be arranged so there is no danger of knocking them off the table or tripping over the leads.

WARNING: If high voltages are to be measured, the arrangement should be such that no one can accidentally come in contact with any of the live parts.

9.60 Wattmeters should be so connected in a circuit that the current coil and the potential coil are at the same potential.

9.61 NEVER touch bare terminals or binding posts while an instrument is energized.

9.62 NEVER connect alternating current to an instrument intended for use on direct current only. Alternating current cannot deflect the pointer of such an instrument, but it can burn out the coil.

9.63 NEVER slam the cover of an instrument. Be sure the nuts on the binding posts are tight, even when the instrument is not in use.

9.64 An instrument should never be left connected, with its pointer deflected off scale, or deflected in the wrong direction.

9.65 Check all connections carefully to make sure that the instrument will not be overloaded before turning on the current.

9.66 Before measuring resistance, always SHUT OFF all power and DISCONNECT batteries (if the equipment being tested employs batteries), and DISCHARGE all capacitors in the equipment under test.

9.67 Do not test devices such as thermocouples, meters, or sensitive relays that can be damaged by the ohmmeter's current. In such cases, use a special bridge circuit.

9.68 The pointer of an ohmmeter of an insulation-resistance indicating instrument (megger) may stand at any point on the scale when the instrument is idle because there is no spring control over the moving element. When the instrument is energized, the pointer should stand at zero if the terminals are shorted, and at infinity if no resistance is connected between them. The instrument can be considered fairly accurate if it reads correctly at these two points. A check of the accuracy at intermediate points can be made by measuring different known resistances, either by resistance boxes or high range direct-current voltmeters or multipliers of known resistance.

9.69 Instrument zero settings should be checked. If the pointer is slightly off zero, reset it to zero by adjusting the external zero adjustment. However, NEVER try to compensate for a bent pointer by moving the zero adjustment.

Use these programed exercises to help check your learning progress.

9-9. Before you move or store a recording instrument, you should remove the ink from the inkwell, clean the pen, and _____ the moving element.	9-9. LOCK REF: 9.37
9-10. When selecting an instrument, two points to keep in mind are: Start with a range that is _____ than the expected reading; and, accuracy is greatest at the _____ end of the scale. *(higher/lower)*	9-10. HIGHER, HIGHER REF: 9.38,9.39
9-11. Because temperature extremes can affect the accuracy of an instrument, it should be allowed to reach _____ _____ before it is used.	9-11. ROOM TEMPERATURE REF: 9.42
9-12. If an instrument reads differently when it is near a short-circuited conductor, its accuracy may be affected by _____.	9-12. STRAY MAGNETIC FIELDS. The effects depend on the strength of the field. REF: 9.46
9-13. When a wattmeter is connected to a circuit, the current coil must always be connected in _____ and the potential coil in _____ with the load. *(series/parallel)*	9-13. SERIES, PARALLEL REF: 9.52, 9.53
9-14. The secondary of a potential transformer must always be _____-_____ through a high resistance. A current transformer secondary must be _____-_____ when not in use.	9-14. OPEN-CIRCUITED, SHORT-CIRCUITED REF: 9.54,9.57
9-15. Before connecting an ohmmeter to a circuit, disconnect all electrical power, and discharge all _____ in the circuit.	9-15. CAPACITORS REF: 9.66
9-16. To calibrate an ohmmeter, when the instrument is energized, the pointer should stand at zero when the leads are _____-_____ and infinity when the leads are _____-_____.	9-16. SHORT-CIRCUITED, OPEN-CIRCUITED REF: 9.68

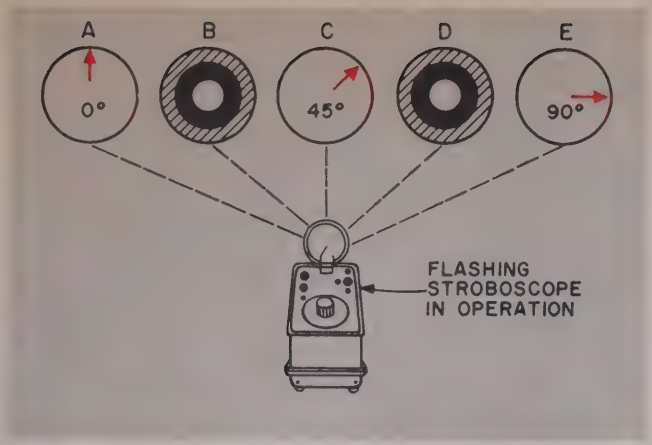


Fig. 9-8. Producing a slow-motion image with a stroboscope.

The Stroboscope

9.70 A stroboscope is an instrument that produces the optical illusion of slowed or stopped motion. This is accomplished by permitting periodic observations at a rate at or near synchronism with the apparatus being observed.

9.71 The stroboscope is in some respects like a movie camera. The camera shutter, operating at high speeds, cuts the action into a series of small elements in which movement is not apparent in any one element.

9.72 Figure 9-8 illustrates how a stroboscope produces a slow-motion image. The stroboscope flashes once every 1-1/8 revolution of the disk. In A, a single flash catches the disk in its 0° position. In B, while the stroboscope is not flashing, the disk, rotating clockwise, makes more than a full revolution. In C, the next flash catches the disk at it 45° position. The next flash, in E, occurs after the stroboscope has made another 1-1/8 revolution. The eye, retaining each image it receives for a split second, weaves A, C, and E into an image of apparent slow forward motion.

Operating Principles

9.73 When a periodically moving object is illuminated by flashes of light from a stroboscope, the object appears to move at a speed equal to the difference between the flashing speed of the stroboscope and the speed of the object. When this difference is zero, the object appears stationary. Thus, if the moving object appears stationary, the speed of the object can be determined from the stroboscope flashing rate, which is indicated on a calibrated dial. On most stroboscopes, the flashing-rate calibration is given in terms of flashes per minute (numerically equal to rpm).

9.74 A movie-camera shutter can produce a stroboscopic effect, because of the action of the camera shutter. If, for example, you are allowed momentary glimpses of a spinning pulley exactly 450 times a minute, and if that pulley is spinning at the rate of 450 revolutions a minute, then, at each glimpse of the pulley, it will be in the same position. If you slow the stroboscope speed, each flash illuminates the pulley at a slightly later part of its cycle, and the pulley appears to rotate slowly forward.

9.75 Thus, by controlling the rate at which you interrupt vision, you can produce a replica of the high-speed motion at almost any slow speed you desire, forward or backward.

9.76 Intermittent observation can be provided by intermittent illumination of the object being viewed. An industrial stroboscope is basically a lamp plus the electronic circuits necessary to turn it on and off very rapidly – at rates as high as 150,000 flashes per minute.

9.77 Electronic control of a flashing lamp permits accurate setting of the flashing rate, and this capability leads to the use of stroboscopes as tachometers which are sometimes called "strobotacs." One advantage of the stroboscope over a tachometer is that it requires no mechanical connection to the device whose speed is being measured.

9.78 The stroboscope absorbs no power from the device whose speed it measures, and it can be used with delicate mechanisms and low-torque motors. It is fast enough to catch the highest-speed motion, and is much more accurate than most mechanical tachometers. To serve as a tachometer, a stroboscope must include its own flashing-rate control circuits and calibrated dial.

9.79 A Strobotac can flash at rates down to 110 flashes per minute although flicker is pronounced at speeds below 600 rpm. At slow speeds, the eye

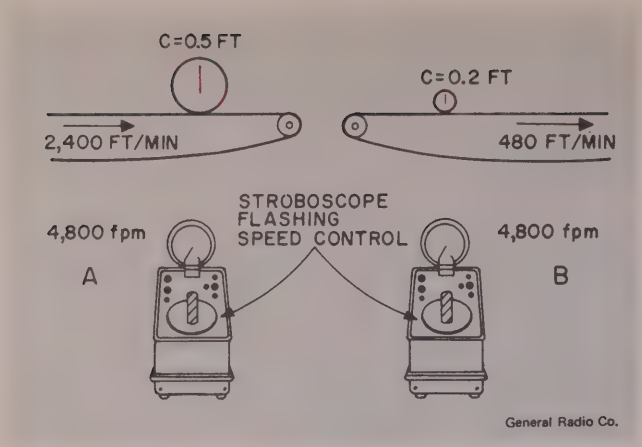


Fig. 9-9. Use of a surface wheel and a stroboscope.

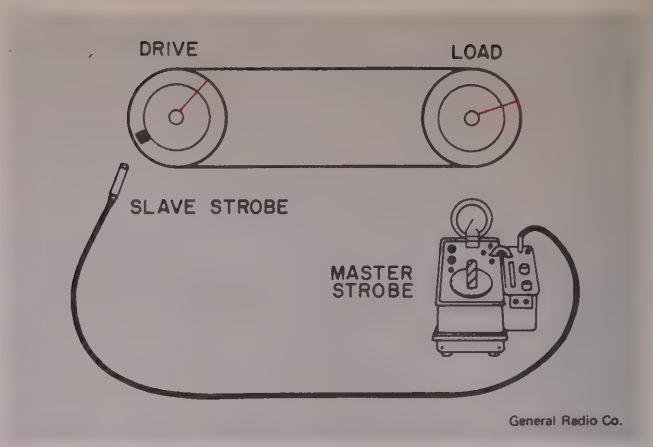


Fig. 9-10. Using a stroboscope to measure belt slippage.

responds to peak rather than average intensity, and the peak intensity in turn increases by a factor of six as the flashing-rate range control is switched to the next slower speed range. The resultant increase in brightness makes it easier to observe the subject, but it also intensifies the annoyance of flicker.

9.80 In adjusting the stroboscope flashing rate for a single, stationary image, you must be careful to avoid becoming confused when the object being viewed is symmetrical. A four-bladed fan, for instance, will appear stopped when the stroboscope is flashing at both twice and at four times the speed of the fan. This is solved easily by chalk-marking one of the four blades. The chalk-mark is then distinct only at synchronism.

9.81 Stroboscopes are commonly used to measure the difference in speed between a belt-driven device and the driving shaft; that is, the slip introduced by the belt. The Strobotac is used for detecting pulley or wheel wobble, for creating animated stage effects, for measuring vibration frequency and vibratory modes of turbine blades, or any extremely fast motion, or speed of rotating equipment.

9.82 Frequently it is desirable to measure the linear speed of a device rather than the number of revolutions per minute. The surface speeds of drums, wheels, and rollers and the linear speeds of belts and pulleys can be measured stroboscopically with the aid of a "SURFACE-SPEED WHEEL."

9.83 A surface-speed wheel is a disk whose circumference is such that, when the disk is caused to rotate by contact with a moving object such as a belt, the surface speed of the object is related to the rotating rate of the disk. This relationship is used to determine the linear speed.

9.84 Surface speed wheels are sized and marked for simple conversion of linear speed into revolutions per minute. When using one of these wheels, hold it firmly enough against the moving surface to prevent slippage, but not so firmly that it introduces drag. Since the accuracy of conversion from linear to rotational speed depends chiefly on the size of the wheel, you should measure the diameter of the speed wheel occasionally to check for wear.

9.85 Figure 9-9 illustrates the use of a surface wheel. In Fig. 9-9(A) the larger of the two surface speed wheels gives a single stationary image when the flashing rate is twice the surface speed in feet per minute and the belt speed is 2,400 feet per minute. In Fig. 9-9(B) the smaller of the two surface speed wheels gives a *double* stationary image when the flashing rate is 10 times the surface speed (in feet per minute), and the belt speed is 480 feet per minute.

9.86 Figure 9-10 illustrates a method of measuring belt slippage by observing the load under stroboscopic flashes photoelectrically synchronized with the drive shaft. Another method is done by adjusting the stroboscope flashing rate for stopped image of a drive shaft, then carrying the strobe to loads and checking them. A difference in rates indicates slippage.

SELF-CHECK QUIZ

9-1. The main advantage of a strip-chart recorder is that it provides a

a. record you can see at a glance
b. record for long unattended periods
c. daily record on a single sheet
d. record of voltage and current, using the same instrument

9-2. What type drive motor is likely to provide the most reliable record over a long period of time?

a. Hand-wound spring drive
b. Synchronous motor drive
c. Electric motor wound spring drive
d. Battery powered motor drive

9-3. An inkless recorder is recommended for circuits in which

a. there is excessive vibration
b. excessive heat or cold may be encountered
c. values fall within a narrow range
d. readings may fluctuate rapidly

9-4. A round-chart recorder has the greatest advantage where

a. each day's record must be kept individually
b. the instrument is left unattended
c. a record is needed over a long period of time
d. values fluctuate rapidly

9-5. When selecting an instrument, be sure its range is

a. higher than the value being measured
b. below that of the circuit being tested
c. mid-way on the scale
d. on the lower third of the scale

9-6. Which of the following disturbances may permanently affect instrument accuracy?

a. A short circuit on a nearby conductor
b. Operating near an unshielded instrument
c. Passing through a stray magnetic field
d. All of the above

9-7. When connecting a wattmeter into a circuit, be sure the terminals are connected so that the

a. current coil is in parallel; potential coil in series
b. potential coil is in parallel; current coil in series
c. current and potential coils are in parallel
d. current and potential coils are in series

9-8. When current transformers are not in use, the secondary should be

a. fused
b. open-circuited
c. short-circuited
d. grounded with the primary

9-9. Before connecting an ohmmeter to a circuit, take steps to ensure that

a. the circuit is energized
b. all capacitors are discharged
c. all switches are closed
d. all inductors are discharged

9-10. When calibrating a megohmmeter with the test probes open, the pointer should stop at

a. any place on the scale
b. the midpoint on the scale
c. zero
d. infinity

ANSWERS TO SELF-CHECK QUIZ

9-1. b. Record for long, unattended periods. REF: 9.08.

9-2. c. Electric motor wound spring drive. REF: 9.18.

9-3. d. Readings may fluctuate rapidly. REF: 9.23.

9-4. a. Each day's record must be kept individually. REF: 9.30.

9-5. a. Higher than the value being measured. REF: 9.38, 9.39.

9-6. a. A short circuit on a nearby conductor. REF: 9.45, 9.47.

9-7. b. Potential coil is in parallel; current coil in series. REF: 9.52, 9.53.

9-8. c. Short-circuited. REF: 9.57.

9-9. b. All capacitors are discharged. REF: 9.66.

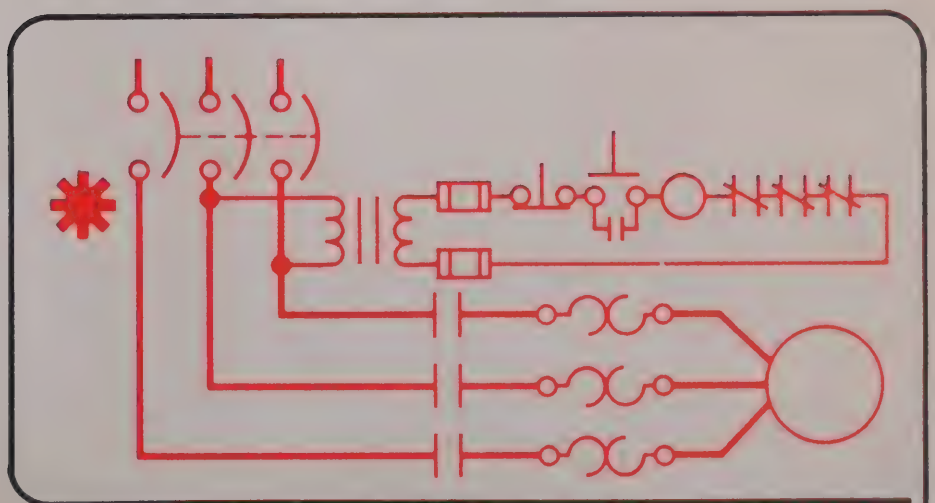
9-10. d. Infinity. REF: 9.68.

LESSON TEN

ELECTRONIC INSTRUMENTS

Plant Engineering®
TRAINING SYSTEMS

Electrical Measuring Instruments



Lesson Ten – Electronic Instruments

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Lesson Ten – Electronic Instruments

Preface

The use of complex and sophisticated control equipment in industry is increasing. The once simple push-button station to start and stop a motor is giving way to complicated control panels. From these panels a complete process of manufacturing can be controlled.

Precise control of machines is required to maintain proper sequence of operation. This type of controlling system requires precision voltage, current, and the waveform measurements of the power supplied to the control panel.

This lesson introduces electronic measuring equipment. Electronic equipment is gaining acceptance in regular industrial electrical maintenance. Electronic measuring equipment will soon become standard because of its almost limitless possibilities. Electronic measuring equipment is not confined to the electronics trade alone.

The Vacuum-Tube Voltmeter

10.01 The vacuum-tube voltmeter, or VTVM, as it is generally called, is similar to the VOM explained in an earlier lesson. The VTVM uses many of the basic circuits of the VOM.

10.02 There are some advantages the VTVM has that the VOM does not. One advantage is that the VTVM has a mucher higher input impedance. The input impedance is about 11 megohms compared to the several thousand ohms of the VOM. The high input impedance does not load the circuit under test nearly as much as the VOM does. The VTVM has better provisions for measuring A-C than does the VOM and is more sensitive.

10.03 There are also some disadvantages. The VTVM requires a high voltage supply. The VOM requires none. The VTVM requires a 120 volt A-C source for operation. The VOM requires none. Both instruments require a battery for resistance measurements. The VTVM does not measure current. The VOM does. Before it is used, the VTVM requires a warmup period. This stabilizes the electronic circuits. The VOM does not require warmup.

10.04 The circuit, which is the heart of the VTVM and allows it to measure voltages and resistances with high input resistance accurately, has two electron tubes. These tubes are so connected that the current flow through both of them is equal. To ensure that the same amount of current flows through the tubes, a balancing potentiometer or zero-adjust control is provided on the meter panel as shown in Fig. 10-1.

10.05 A microammeter is connected in the tube circuit. With the circuit balanced, the meter indicates zero voltage. Before the meter is used, the meter must be zeroed by adjusting the zero-adjust control.

10.06 If a positive voltage is applied to one tube, current flow through the tube will increase and unbalance the circuit. The current flow through the other tube remains the same. This unbalance

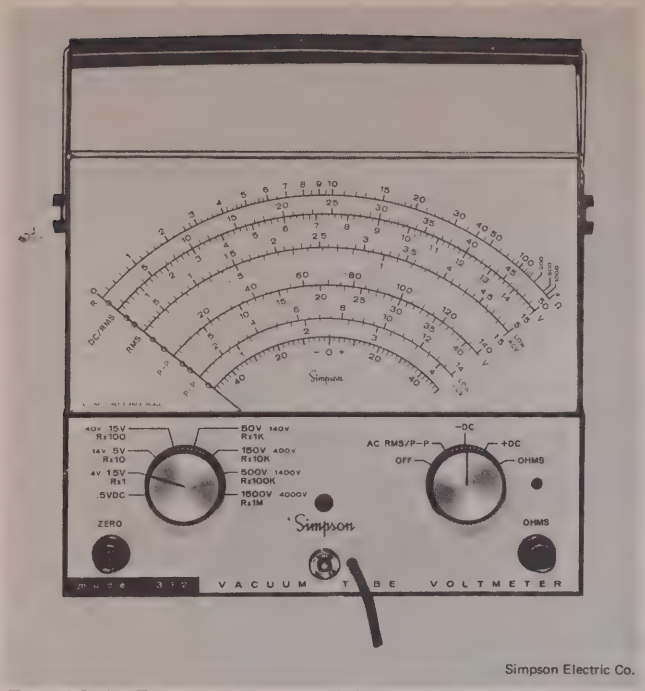


Fig. 10-1. Front panel of VTVM.

causes current to flow through the meter and indicates the presence of voltage.

10.07 It may seem to be a rather complicated method of getting current to flow through a meter, but a very important advantage is gained. The VTVM circuit draws only a very small amount of current from the circuit being measured. Because the input impedance of most VTVMs is about 11 megohms, the little amount of current drawn from the circuit is usually ignored. (A VOM must use current from the circuit under test to operate the meter.)

10.08 To measure voltages, a simple D-C multiplier circuit like that shown in Fig. 10-2 is used. A number of precision resistors are arranged in a series circuit with one end of the string grounded. Any voltage to be measured is applied across these resistors. Each resistor is connected to a wafer-switch terminal so that the voltage may be taken from any point on the resistor string. These multipliers work in much the same way as they do in a VOM, but in a VOM the resistors are in series with the meter.

A-C Voltage Measurements

10.09 The VTVM has provisions for measuring A-C voltages. As in the VOM, the A-C voltage must be rectified (changed to D-C) before it is measured by the electronic circuit. Diode rectifiers are used. The rectified A-C then goes through the D-C multiplier circuit shown in Fig. 10-2. The same voltage scales are used for D-C and A-C.

Resistance Measurements

10.10 The resistance-measuring circuit in a VTVM is separate. A series of resistors are used with a 1.5 volt battery between the last resistor and ground as shown in Fig. 10-3.

10.11 Each resistor junction is connected to a wafer-switch terminal. The rotating arm of the switch is connected to a probe and also to an electron tube. The second probe is connected to ground.

10.12 When a resistor is to be measured, the probes are placed across the resistor. This places the unknown resistance across the resistors selected by the range switch. The electron tubes will measure the amount of voltage present. This voltage is in direct proportion to the amount of resistance in the resistor string. The resistance of the unknown resistor is read on the meter scale. A typical VTVM measures resistance from zero ohms to 1000 megohms.

Fig. 10-2. VTVM range switch and multipliers.

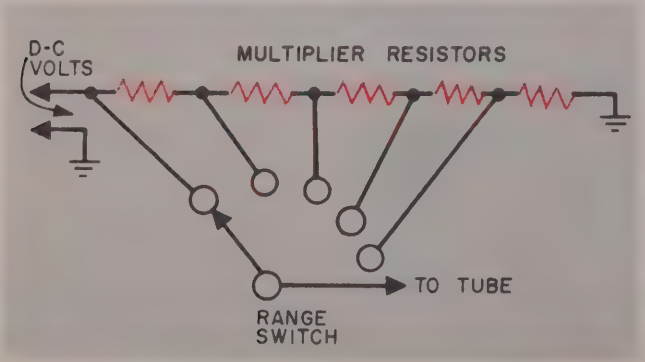
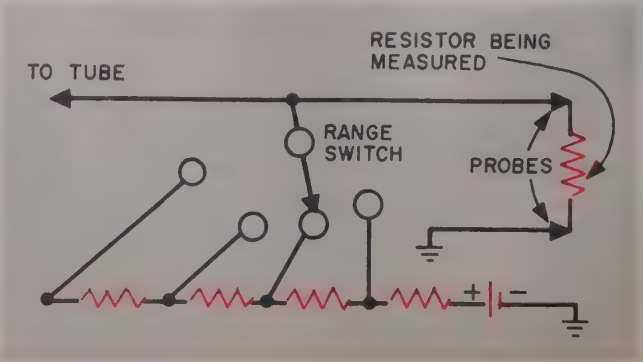


Fig. 10-3. VTVM circuit for measuring resistance.



Use these programed exercises to help check your learning progress.

10-1. A vacuum-tube voltmeter (VTVM) is similar to the volt-ohm-milliammeter (VOM) because it uses many of the same basic _____.	10-1. CIRCUITS REF: 10.01
10-2. Name three advantages a VTVM has that a VOM does not have. 1. _____ 2. _____ 3. _____	10-2. 1. High input impedance. 2. Better provisions for measuring A-C. 3. More sensitive. REF: 10.02
10-3. Name four disadvantages a VTVM has that a VOM does not have. 1. _____ 2. _____ 3. _____ 4. _____	10-3. 1. Requires higher voltage supply. 2. Requires 120 volt A-C source for operation. 3. Does not measure current. 4. Requires warm up period to stabilize. REF: 10.03
10-4. To measure resistance, both the VTVM and VOM require a _____.	10-4. BATTERY or D-C supply REF: 10.03
10-5. The heart of the VTVM is two _____ _____.	10-5. ELECTRON TUBES REF: 10.04
10-6. The current drawn from the circuit by a VTVM is very _____.	10-6. SMALL REF: 10.07
10-7. On a VTVM the meter scales for A-C and D-C voltages are the _____.	10-7. SAME REF: 10.09
10-8. A typical VTVM measures resistance from _____ to _____.	10-8. ZERO to 1,000 megohms REF: 10.12

10.13 Alternating current has four important characteristics. These are: amplitude, frequency, waveform, and phase. The amplitude of an A-C voltage is measured with a voltmeter. The voltmeter indicates the rms value of A-C. The oscilloscope shown in Fig. 10-4 is used to measure peak values and peak-to-peak values of A-C. The "scope" not only measures these values of A-C voltage, but it also checks frequency, phase, and the waveshape.

10.14 Alternating current is much easier to understand if it is pictured graphically. This is shown in Fig. 10-5. The oscilloscope is an instrument that draws, electronically, a graphical picture of an A-C sine wave. The vertical axis of the graph is used to show changes in amplitude, while the horizontal axis is plotted for time, or frequency. The curve that is drawn when amplitude is plotted against time is called the "waveshape" or sine wave of A-C.

10.15 To plot a graph of A-C a dot of light is used in the oscilloscope. The dot of light is produced by a beam of electrons inside a "cathode ray tube"

Fig. 10-4. An oscilloscope.

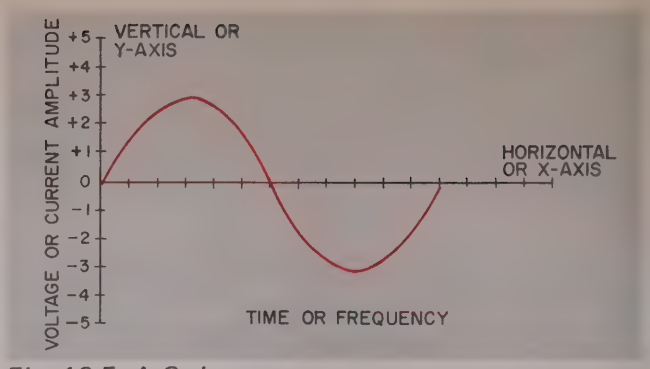


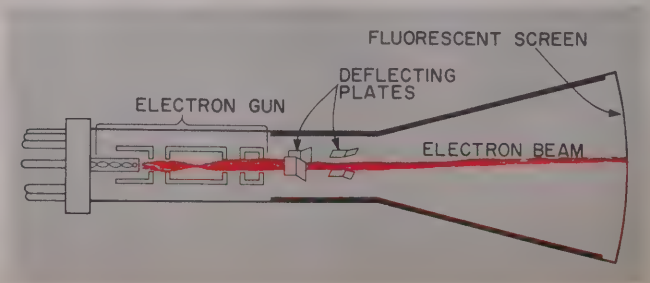
Fig. 10-5. A-C sine wave.

(CRT). Fig. 10-6 illustrates the various parts of a cathode ray tube.

10.16 The CRT is a tube similar to the picture tube in a TV set. It contains an electron gun, two pairs of deflection plates, and a fluorescent screen. The electron gun produces a beam of electrons that strike the fluorescent screen to produce light. The fluorescent material coats the inside face of the tube's viewing screen. The electron beam is traveling at a very high speed when it strikes the fluorescent screen. The amount of light the beam produces when it strikes the screen depends on the speed the electrons are traveling, and the number of electrons in the beam. This is determined by a control, called the "intensity" or "brightness" control, on the front of the scope panel. The intensity control should not be turned to a point of excessive brilliance or damage to the fluorescent screen may result.

10.17 The electron gun focuses the electron beam so it comes to a sharp point when it reaches the fluorescent screen. Since this spot is to be used to draw a graph, it will be able to draw more detail in the graph with a small dot than with a large one. The size of the dot produced by the electron gun can be adjusted by a control on the front of the scope panel, called the "focus" control.

Fig. 10-6. Cathode-ray tube.



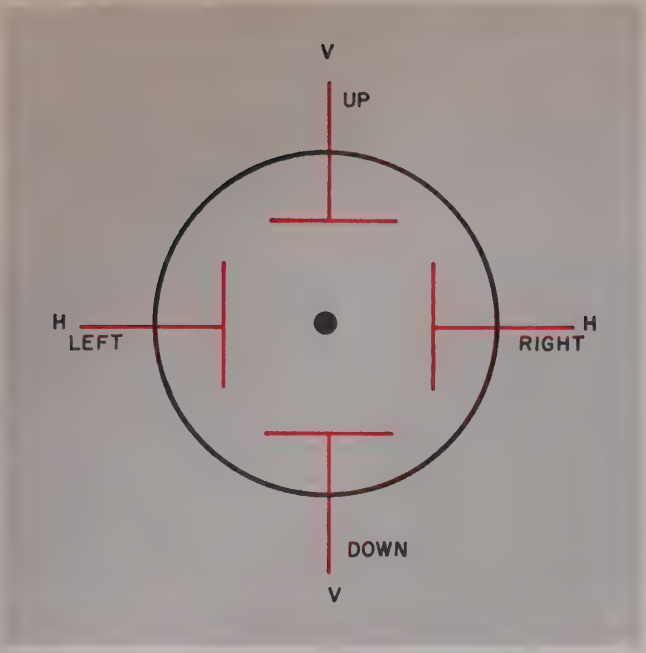
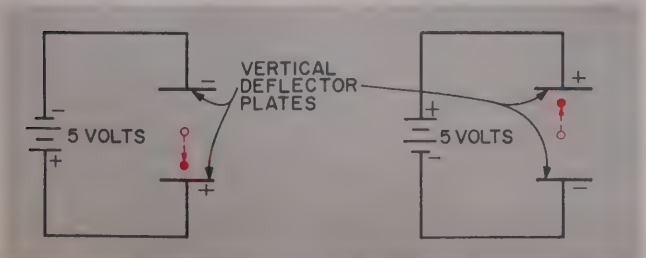


Fig. 10-7. End view of CRT deflecting plates.

10.18 If you use a pencil to draw an A-C sine wave, you must move it up and down and sideways. In the scope, up-and-down movement of the electron beam is caused by the "vertical deflection plates." Horizontal movement is caused by the "horizontal deflection plates." an end view of these plates is shown in Fig. 10-7.

10.19 How do the deflection plates cause the dot of light on the screen to move? The dot is produced by a beam of electrons passing between the deflection plates. Electrons have a negative charge. Like charges repel each other, and unlike charges attract each other. Voltage is connected between one pair of deflection plates – the plate attached to the negative terminal of the battery has a negative charge, and the plate attached to the positive terminal of the battery has a positive charge. The beam, passing between these plates, is repelled from the negatively-charged plate, and attracted toward the positively-charged plate. The direction of movement is determined by the polarity of the battery voltage as shown in Fig. 10-8.

Fig. 10-8. Position of dot as voltage is varied on vertical plates.



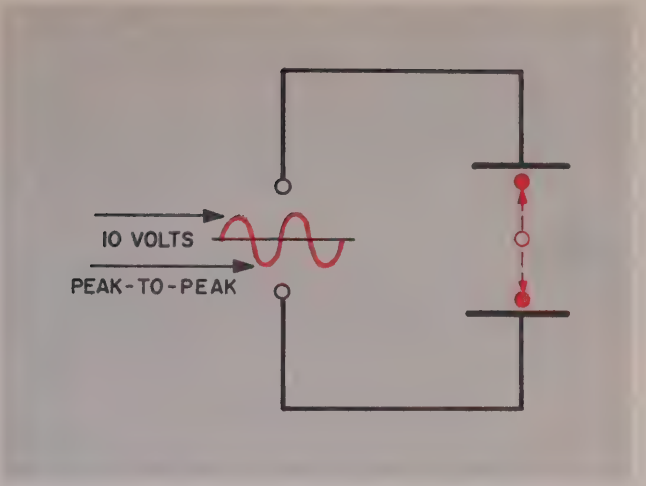


Fig. 10-9. A-C voltage applied to vertical deflection plates.

10.20 The action of the battery voltage applied to the horizontal deflection plates is the same as the voltages applied to the vertical plates, except that the movement of the beam is in the horizontal direction.

10.21 There are two centering controls located on the front panel. These centering controls permit adjustment of the D-C voltage applied to the deflection plates. With these controls, the electron beam can be moved up and down or left and right as desired. Centering controls are often called "positioning" controls.

10.22 A-C voltages are applied to the deflection plates in addition to the D-C voltages. The effect of A-C is to make the beam move up and down or from side to side in step with the changes in amplitude and frequency of the A-C. In other words, when A-C at a frequency of 60 Hz is applied to the vertical deflection plates, the beam moves up and down 60 times per second. The length of travel of the beam is determined by the peak-to-peak amplitude of the A-C voltage. This is illustrated in Fig. 10-9. Note that the peak-to-peak voltage applied to the vertical deflection plates is 10 volts. If the amount of voltage is doubled, the distance the beam travels will also double. The A-C voltage that is applied to the vertical deflection plates is the voltage the oscilloscope graphs. In order to reach the vertical deflection plates, the voltage is applied between the vertical input binding post and ground. These terminals are

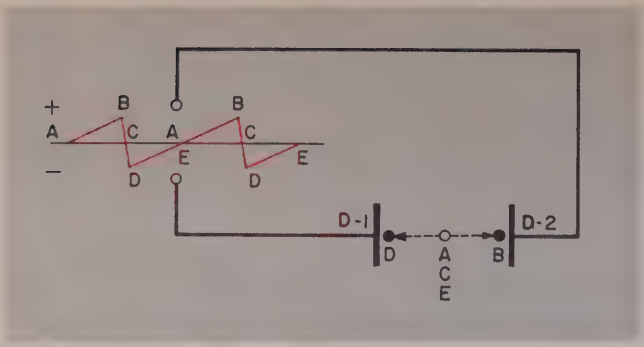


Fig. 10-10. Sawtooth voltage applied to horizontal deflecting plates.

usually located at the lower left hand corner of the control panel.

10.23 When the A-C voltages applied to the deflection plates have a frequency higher than 10 Hz, you cannot see the dot. You see a line whose length is equal to the distance the beam travels. The line is seen because of a phenomenon called the "persistence of vision." Because of this persistence of vision, the eye always sees light for a fraction of a second after the light disappears. You can see this effect demonstrated by twirling a flashlight in a circle. If it is twirled fast enough the illusion of a large circle of light is created. We depend on persistence of vision to create the illusion of a stationary graph on the scope even though it is being made by a moving dot of light.

10.24 To graph voltages of different values, a control is provided in the scope to control the size of the A-C voltage that reaches the vertical plates. This control is called the "vertical gain" control. By advancing the vertical gain control, the height of the line or pattern will increase. The control is sometimes called the "height" control.

10.25 To increase the *range* of the vertical gain control, most scopes include a vertical attenuator switch. For extremely small input voltages, the switch is set at its lowest range setting (the X-1 position). For voltage inputs of 10 volts or more, the next range position should be used.

Sweep

10.26 Rather than a voltage that maintains one value of polarity, the A-C voltage that is applied between the horizontal deflection plates must cause the electron beam to move steadily across the scope screen from left to right, and then allow it to move back to the left very rapidly. A sawtooth-shaped voltage similar to that illustrated in Fig. 10-10 will accomplish this. This figure also illustrates how a sawtooth voltage applied to the horizontal plates affects the beam.

10.27 For example, at point A on the sawtooth, plate D-1 and plate D-2 are indicated as being at zero potential; the electron beam is in the middle of the screen. In time, the voltage at plate D-2 increases the positive direction until, at point B on the sawtooth, plate D-2 is at maximum positive potential. The beam is then attracted as far to the right as it can go (considering the peak-to-peak voltage applied).

10.28 Note that from point B to point C on the sawtooth, the voltage decreases to zero very rapidly. This means that the beam will move very rapidly back to the center of the screen. At point C the polarity of the voltage changes, and plate D-1 becomes positive with respect to plate D-2. The voltage increases to maximum very rapidly with this polarity. (C to D on the sawtooth.) This causes the beam to move rapidly to the left side of the screen. The voltage then decreases slowly to zero (D to E on the sawtooth), which allows the beam to return again to the center of the screen.

10.29 If the sawtooth voltage continues, the beam will move back and forth across the screen, moving slowly from left to right, and rapidly from right to left. The movement of the beam from left to right is called the "trace," and the fast movement from right to left the "retrace." The oscilloscope uses only the trace to draw its graph. The retrace is unnecessary, and it is either killed electronically or barely seen, because of its speed. Figure 10-11 helps to illustrate how the sawtooth voltage causes the electron beam to travel across the screen, thus providing a time base on the scope screen.

10.30 While the beam is moving steadily across the screen, the A-C voltage sine wave applied to the vertical deflection plates is changing. Thus, the vertical plates cause the beam to move up and down. The vertical-input voltage is spread out in time, thus causing the voltage waveform to appear on the scope screen.

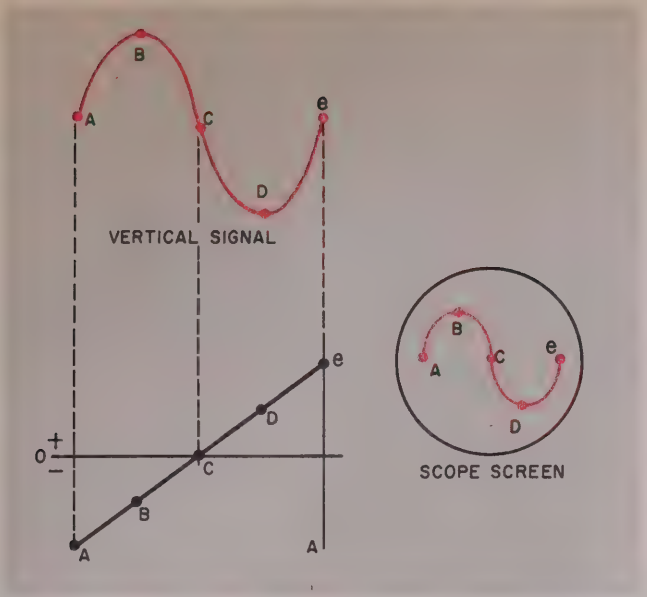


Fig. 10-11. How sawtooth voltage causes electron beam to travel horizontally.

10.31 In order for one cycle (pattern) to appear on the scope, the horizontal and vertical deflection frequencies must be the same. If this is so, the beam, when it finishes tracing out one sine wave, will fly back and trace another right over the first, producing the illusion that the wave is standing still. The scope can display two cycles of A-C only if the frequency of the horizontal sweep is one-half that of the observed waveform. Then, the vertical A-C will have time to go through two of its cycles while the horizontal goes through only one.

10.32 The ratio of 1:1, 2:1, and so on, between the vertical frequency and the horizontal frequency must be precise, or the patterns traced will not be superimposed on each other, and the resulting pattern will not be recognizable. The horizontal timing can be adjusted accurately with the horizontal frequency controls. However, unless the horizontal sweep is "locked in," it will tend to drift. To prevent this drifting, a "sync control" is used. After the horizontal frequency control has been properly adjusted for one or two patterns, the sync control is advanced just far enough to lock the pattern.

10.33 A coarse-frequency switch on most oscilloscopes is used to extend the range of the horizontal, fine-frequency control. This coarse-frequency switch has several positions. If a 60 Hz sine wave is to be displayed, the coarse-frequency switch should be set to the 15-90 position. The horizontal frequency control can then be adjusted for the desired number of cycles in the pattern.

10.34 Another control on the front of most oscilloscopes is called the "blanking control." The purpose of the blanking control is to eliminate the line caused by the beam retracing from right to left.

10.35 A test signal binding post is on the front panel of most oscilloscopes. Its purpose is to provide a voltage to check the scope's operation, and also to calibrate the scope for peak-to-peak voltage checks. Generally the test signal is a 60 Hz voltage.

10-9. The oscilloscope is used to check the _____, _____, and _____ of A-C voltage.	10-9. FREQUENCY, PHASE, and WAVESHAPE REF: 10.13
10-10. A graphic picture of an A-C sine wave is drawn _____ by an oscilloscope.	10-10. ELECTRONICALLY REF: 10.14
10-11. When an electron beam produced by the electron gun strikes a fluorescent screen, _____ is produced.	10-11. LIGHT REF: 10.15
10-12. The electron beam in a scope is deflected vertically and horizontally by _____ _____.	10-12. DEFLECTION PLATES REF: 10.18
10-13. The A-C voltage applied between the horizontal deflection plates, which causes the electron beam to move steadily across the scope screen, is called a _____ voltage.	10-13. SAWTOOTH REF: 10.26
10-14. The movement of the electron beam on the oscilloscope screen from left to right is called the _____.	10-14. TRACE REF: 10.29
10-15. The fast movement of the electron beam from right to left is called the _____.	10-15. RETRACE REF: 10.29
10-16. The retrace is barely seen on the oscilloscope screen because of its _____.	10-16. SPEED REF: 10.29

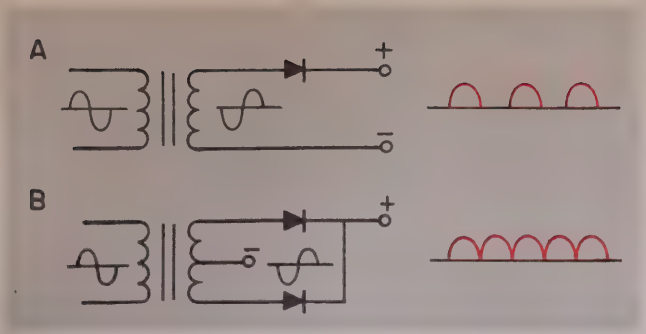


Fig. 10-12. (A) Half-wave circuit and output waveform. (B) Full-wave circuit and output waveform.

Intensity and Focus Controls

10.36 The intensity control has the scope's off-on switch. The intensity control is turned to the right to apply power to the electron tubes in the instrument. The intensity control is adjusted to obtain normal beam brightness. A dot is seen on the screen, if the vertical- and horizontal-gain controls are set to zero, and the positioning controls are set to mid-range. To properly focus the dot or trace, the focus control is adjusted to make the dot as small as possible.

10.37 To center the dot or trace on the screen, two centering (positioning) controls are provided. The beam moves up or down, when the vertical-centering control is turned. In the same manner, the beam moves left or right on the screen when the horizontal-centering control is turned.

10.38 Trace-width depends on the horizontal-gain control setting. Trace-height depends on the vertical-gain control setting. To obtain a vertical trace, a wire is connected from the vertical-input terminal to the 1V peak-to-peak terminal on the scope panel. This will apply a 60 Hz sine wave to the vertical deflection plates. If a 60 Hz voltage sine wave is applied to the scope's vertical-input terminals, a pattern appears on the screen.

10.39 The coarse and fine frequency controls are adjusted to obtain a pattern. The coarse frequency control is set to the correct frequency range. The fine frequency control is adjusted to obtain the desired number of cycles in the pattern.

10.40 The vertical- and horizontal-gain controls are adjusted for a convenient-size pattern. The sync-amplitude control is turned as required to lock the pattern on the screen.

10.41 The same waveform is shown no matter how high or how low the horizontal-gain control is set. However, the waveform seems to change. This is called the "aspect of the displayed waveform." The waveform is often expanded so small details in the pattern can be seen.

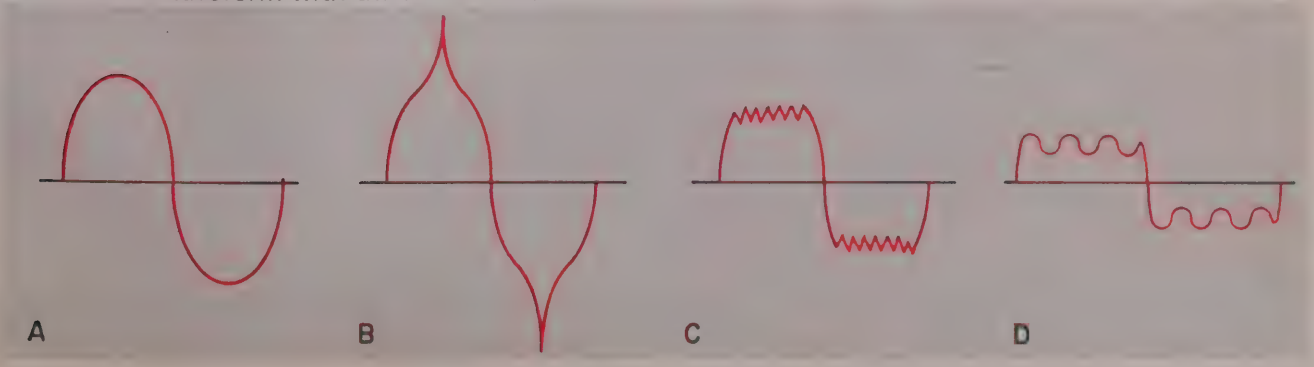
10.42 To become expert at operating the scope, you should practice adjusting the scope controls whenever the opportunity permits.

10.43 The basic control arrangement is the same for all scopes. However, the controls are often located at different places on the front panel, depending on individual models and manufacturers. The names of the controls are sometimes different.

How to Use the Oscilloscope

10.44 The uses of the oscilloscope for electrical troubleshooting are many. It will take time and practice for you to become experienced enough to analyze waveforms and effectively diagnose trouble.

Fig. 10-13. (A) A clean A-C waveform. (B&C) An A-C waveform with electrical interference. (D) 60 Hz waveform with third harmonic.



Simpson Electric Co.

Fig. 10-14. Digital display.

10.45 The waveforms in Fig. 10-12(A) are those of a half-wave rectifier circuit. The half-wave rectifier changes or uses one-half of an A-C cycle, while the waveform in Fig. 10-12(B) is that of a full-wave rectifier, which shows both halves of an A-C cycle. D-C power supplies used for D-C equipment have similar waveforms.

10.46 Knowing what waveform should be seen on the oscilloscope is the first step. If no waveform, or a waveform other than normal, is seen, then tracing the circuit to locate the trouble can be done effectively.

10.47 Another use of the scope is locating the source of interference of radio reception. Arcing is one major source of static picked up by radio receivers. The arcing cannot be found by visual means. The oscilloscope will help to locate the equipment that is causing the static. The sine wave of the power coming into the plant should be clean, as shown in Fig. 10-13(A). With electrical interference a sine wave may look like Fig. 10-13(B) or 10-13(C).

10.48 Another problem that may exist is having a strong third harmonic on the A-C lines. (The third harmonic is 3 times the fundamental frequency.) For a 60 Hz system the third harmonic is 180 Hz. An A-C sine wave with a third harmonic may appear similar to the waveshape illustrated in Fig. 10-13(D).

10.49 The oscilloscope is a great aid to trouble-shooting electronic controls used on many machines today.

Solid-State Instruments

10.50 The VTVM was the first instrument introduced as an electronic troubleshooting instrument. This instrument uses vacuum tubes, which are being replaced by transistors. With the use of transistors, the phrase "solid-state" pertains.

10.51 A vacuum tube consists of electrodes spaced at a given distance in a glass envelope. The air is removed from the glass envelope to form a vacuum.

10.52 The transistor is made from solid matter put together like a sandwich; there is no vacuum. The sandwich is enclosed in a metal or plastic container for protection.

10.53 Many measuring instruments are made using transistors. These instruments are physically smaller, lighter, and more compact than electron tube models.

10.54 A solid-state voltmeter uses transistors in its circuitry. It is a very accurate instrument. The more sophisticated voltmeters use a digital read-out display, as shown in Fig. 10-14.

10.55 The length of time the numbers are displayed can be controlled by a knob. The display time can be from a fraction of a second to several minutes. At the end of the display time, a new reading is automatically taken and displayed. If a circuit is being adjusted for proper voltage, a short display is required. After the circuit is adjusted and the voltage is to be monitored, then a longer display time is used.

10.56 The solid-state voltmeter is direct-reading. The decimal point is in the proper position. The voltmeter will tell you whether the voltage read is positive or negative with reference to the common lead. The solid-state voltmeter is very sensitive and is capable of reading microvolts (millionths of a volt).

10.57 A solid-state ohmmeter operates on the same principle as the solid-state voltmeter; that is, it displays the resistance reading.

10.58 A solid-state frequency meter displays the frequency in Hertz. Since frequency is a function of time, time measurements may also be displayed.

Use these programed exercises to help check your learning progress.

10-17. To make the dot or trace on the scope screen as small as possible, the _____ control is adjusted.	10-17. FOCUS REF: 10.36
10-18. The brightness of the pattern on the scope screen is controlled by an _____ control.	10-18. INTENSITY REF: 10.36
10-19. The centering of the dot or trace on the scope screen is controlled by the _____ control.	10-19. CENTERING REF: 10.37
10-20. To see small details in a pattern displayed on the oscilloscope screen, the waveform should be _____.	10-20. EXPANDED REF: 10.41
10-21. In electronic instruments, vacuum tubes are being replaced by _____.	10-21. TRANSISTORS REF: 10.50
10-22. Electronic instruments that use transistors are sometimes called _____ instruments.	10-22. SOLID-STATE REF: 10.50
10-23. More sophisticated electronic instruments use a _____ display.	10-23. DIGITAL READOUT REF: 10.54, Fig. 10-14
10-24. A solid-state digital frequency meter displays the frequency in _____.	10-24. HERTZ or cycles-per-second REF: 10.58

Summary

The vacuum tube voltmeter (VTVM) uses many of the basic principles and much of the circuitry of the VOM.

The VTVM has a number of advantages the VOM does not have. It has a high input impedance, and therefore does not load the circuit under test. Another advantage is the improvement in accuracy of A-C measurements.

The VTVM has some disadvantages. It requires a 120 volt A-C source for operation; and a VTVM does not measure current.

The VTVM, like the VOM, requires a battery for a D-C source to operate the ohmmeter circuit.

An oscilloscope can be used to check frequency, voltage waveform, and A-C phase relationships.

To show the changes that occur during a cycle of A-C voltage, the scope draws a graphic picture of the A-C waveform.

The tool used by the scope to draw its graph is a dot of light. This dot of light is produced by a beam of electrons striking the fluorescent screen inside a tube called a cathode ray tube (CRT).

A CRT consists of three basic parts; an electron gun, two pairs of deflection plates, and a fluorescent screen.

An electron gun produces an electron beam, and makes it come to a sharp point on the face of the CRT.

An "intensity control" changes the density of the electron beam, thereby controlling the brightness of the dot produced on the screen.

A "focus control" changes the point at which the electrons in the beam converge. The focus control adjusts the size of the dot produced on the screen.

The intensity control should not be advanced to a point where the dot gets too bright, because damage to the screen may result.

Centering controls on an oscilloscope position the pattern on the screen. A "vertical centering" control moves the pattern up and down, while a "horizontal centering" control moves the pattern left and right. Centering controls are sometimes called "positioning controls."

A "blanking control" eliminates the retrace line on the oscilloscope.

A "sync-amplitude" control adjusts and locks the pattern on the screen.

If the "coarse-frequency" and "fine-frequency" controls are adjusted, the number of cycles displayed on the screen is changed.

If the coarse-frequency and fine-frequency controls are set too high, a confused crisscross of lines appears on the screen.

The sync-amplitude control must not be turned too high, because the pattern will become distorted.

To have a sine wave pattern appear on the screen of an oscilloscope, a sawtooth voltage is applied to the horizontal deflecting plates. The sawtooth voltage is generated inside the scope.

A test voltage is brought out to a terminal post on the front panel of most oscilloscopes. This test voltage is used to check the operation of the scope, and to calibrate the scope for peak-to-peak voltage measurements.

Electronic instruments that use transistors are frequently called "solid-state" instruments.

Some electronic instruments display the reading numerically, and they are called digital-readout instruments.

SELF-CHECK QUIZ

10-1. One advantage that the VTVM has, that a VOM does not have, is

a. low input impedance
b. high input impedance
c. it does not measure current
d. it measures power only

10-2. One disadvantage that the VTVM has, that a VOM does not have, is

a. low input impedance
b. high input impedance
c. it does not measure current
d. it measures power only

10-3. To measure resistance, both the VTVM and VOM require

a. a battery or D-C source
b. electron tubes
c. 120-volt source
d. internal shunts

10-4. The VTVM is an electronic instrument used to measure

a. voltage and resistance
b. voltage and current
c. voltage and power
d. current and resistance

10-5. A VTVM uses a circuit with

a. an iron vane meter movement
b. electron tubes
c. a frequency multiplier
d. a high current power source

10-6. The oscilloscope is used to check circuit

a. voltage, current, and resistance
b. voltage, current, and power
c. frequency, phase, and waveshape
d. frequency, power, and waveshape

10-7. The picture on an oscilloscope screen is produced by

a. electronics
b. a moving vane
c. a T-V type camera
d. an intensity control

10-8. To observe its pattern on the scope screen, A-C voltage is applied to the

a. sawtooth generator
b. vertical deflection plates
c. horizontal deflection plates
d. electron gun

10-9. What is the waveshape of the voltage applied to the horizontal deflection plates that causes the electron beam to move steadily across the scope screen?

a. A-C sine wave
b. D-C wave
c. Sawtooth wave
d. Square wave

10-10. For a pattern of one cycle of a 60 Hz power source to appear on the scope screen, the horizontal and vertical deflection frequencies must be

a. 30 Hz
b. 40 Hz
c. 60 Hz
d. 120 Hz

ANSWERS TO SELF-CHECK QUIZ

10-1. b. High input impedance. REF: 10.02.

10-2. c. It does not measure current. REF: 10.03.

10-3. a. A battery or D-C source. REF: 10.03.

10-4. a. Voltage and resistance. REF: 10.04.

10-5. b. Electron tubes. REF: 10.04.

10-6. c. Frequency, phase, and waveshape. REF: 10.13.

10-7. a. Electronics. REF: 10.14.

10-8. b. Vertical deflection plates. REF: 10.22.

10-9. c. Sawtooth wave. REF: 10.26.

10-10. c. 60 Hz. REF: 10.31.